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Appendix

COMMONWEALTH OF MASSACHUSETTS
DEPARTMENT OF PUBLIC WORKS

INTERSTATE ROUTE 695
INNER BELT HIGHWAY
BOSTON, CAMBRIDGE AND SOMERVILLE

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LOCATION RESTUDY

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PREPARED BY
H. W. LOCHNER, INC.
BOSTON, MASSACHUSETTS
MAY, 1967

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May 5, 1967

Commissioner Edward J. Ribbs
Commonwealth of Massachusetts
Department of Public Works
100 Nashua Street
Boston, Massachusetts 02114

Re: Location Restudy
Inner Belt Highway
Boston, Cambridge & Somerville

Dear Commissioner Ribbs:

In accordance with verbal directions given to us on September 21, 1966 to analyze a plan presented by the Cambridge Citizens' Advisory Committee for the location of Interstate Route 695 in Boston, Cambridge and Somerville and to compare this alignment with the Brookline-Elm Route, we submit our recommendations in the attached Report.

In the development of this Report, we have carefully reviewed the material presented by the Cambridge Committee in relation to the many factors influencing the location of highways in urban areas including traffic service, subsurface conditions, construction costs, and others. We have also made a comprehensive field study of all the areas involved in this project. The results of the office reviews and field inspections provided the final basis for the information presented in this Report.

Some of the data contained in this document was previously presented in a Report, prepared by this Firm, titled "Summary Report, Boston Metropolitan Inner Belt Highway", dated March, 1966. In that Report two previously proposed Portland-Albany Alignments were considered - one

developed by Goodkind & O'Dea, Inc. for The Department of Public Works and one by Barton-Aschman Associates, Inc. for the City of Cambridge - in addition to several other alignments.

Throughout the preparation of this Report, we have drawn upon the services of many other organizations - The Department of Public Works for right-of-way costs, displacement figures and general coordination; James P. Collins and Associates, Inc. for subsurface investigation; The Architects Collaborative, Inc. for urban considerations; and Goodkind & O'Dea, Inc. and Sverdrup & Parcel and Associates, Inc. for construction cost estimates. We extend our appreciation to these groups for their contributions to this Report.

Very truly yours,

H. W. LOCHNER, INC.

Robert B. Mongrain

Robert B. Mongrain

RBM/pef

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Commonwealth of Massachusetts
Department of Public Works

INTERSTATE ROUTE 695
INNER BELT HIGHWAY
BOSTON, CAMBRIDGE AND SOMERVILLE

LOCATION RESTUDY

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Prepared By
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Boston, Massachusetts
May, 1967

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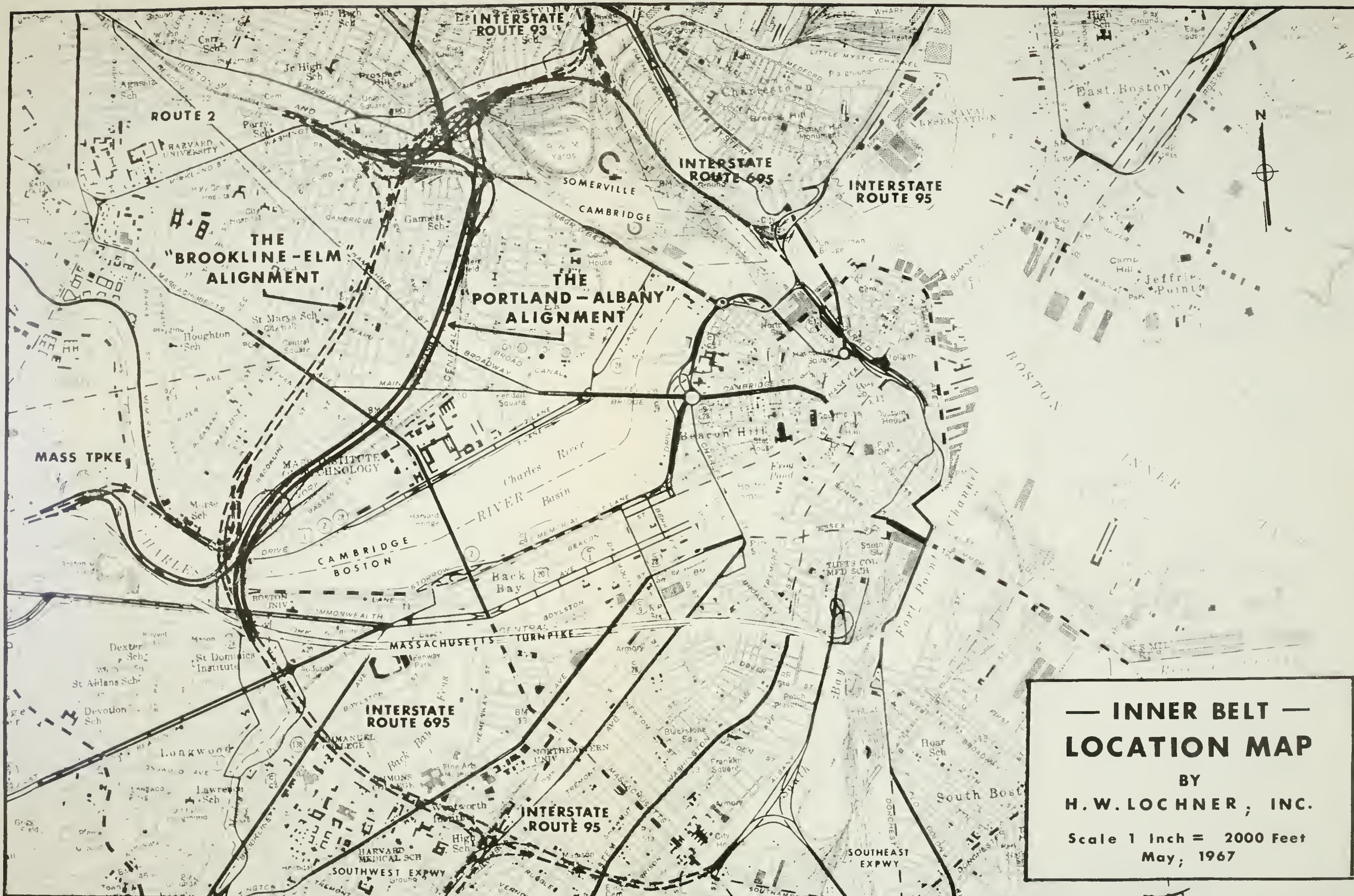
EXHIBITS



— INNER BELT —
LOCATION MAP
BY
H.W. LOCHNER, INC.
Scale 1 Inch = 2000 Feet
May, 1967
INTERSTATE ROUTE 93
ROUTE 2
INTERSTATE ROUTE 695
INTERSTATE ROUTE 95
THE "BROOKLINE-ELM" ALIGNMENT
THE "PORTLAND-ALBANY" ALIGNMENT
MASS TPKE
MASSACHUSETTS TURNPIKE
SOUTHWEST EXPWY
SOUTHEAST EXPWY
SOMERVILLE
CAMBRIDGE
BOSTON
Charlestown
East Boston
Beacon Hill
Back Bay
South Boston
Charles River Basin
HARVARD UNIVERSITY
Longwood
Jeffries Point
N

EXHIBIT 1

I. INTRODUCTION

Background Information

This report presents an analysis of an Inner Belt Route through Cambridge, including major portions of adjoining sections in Boston and Somerville, recently submitted to the Department of Public Works by a group known as the Cambridge Citizens' Advisory Committee.

Over the past two years this Committee has vigorously opposed an Inner Belt Route through Cambridge contending that it had never been adequately demonstrated that an Inner Belt was needed. However, realizing that in all probability a highway would be constructed through Cambridge, this group developed a schematic alignment which, in their opinion, was less damaging to Cambridge than the alignments considered by the Department of Public Works.

A little over one year ago, in response to the urging of the Cambridge Committee, the Cambridge City Council retained the engineering firm of Barton-Aschman Associates, Inc. to develop in greater detail the

schemes advanced by the Committee. Three alternates suggested by the Committee were used by Barton-Aschman Associates in developing their recommended alignment along the Portland-Albany corridor which was presented in the report "Alternate Alignments for the Inner Belt Through the City of Cambridge, Massachusetts", dated February 15, 1966. This recommended plan was submitted by the City to the Department of Public Works for evaluation and for comparison with other route locations developed by the Department.

At the request of the Department, H. W. Lochner, Inc. evaluated the Barton-Aschman recommendation, as well as the other Inner Belt alignments developed by the Department and its consultants, and concluded that the Brookline-Elm Alignment presented the best over-all solution for the Inner Belt in Cambridge and recommended that this alignment be adopted. This recommendation was contained in a Report titled, "Summary Report, Boston Metropolitan Inner Belt Highway, Cambridge Section", dated March 11, 1966. Subsequently, in March of 1966, the Department selected the Brookline-Elm Route as the most desirable alignment and submitted it, with a recommendation for approval, to the Bureau of Public Roads.

In late October, 1966 the Cambridge

Committee requested that the Department restudy the Inner Belt Route in Cambridge. Specifically, they wanted their latest scheme for the Portland-Albany corridor developed and evaluated to the same degree of detail as the Brookline-Elm Alignment. Accordingly, the Department's recommendation on the Brookline-Elm Alignment was withdrawn from the Bureau of Public Roads and a detailed study of the Cambridge Committee plan was started.

Necessity for the Inner Belt

A circumferential Belt Highway connecting the radial expressways as they approach the heart of large Metropolitan areas such as Boston, is a universally accepted necessity. This method is being successfully applied in Chicago, Washington, Indianapolis and many other major cities. However, locally, there are several groups that claim that a Belt Route, specifically in Cambridge, is not necessary.

The need for an Inner Belt Highway was recognized in the 1948 Report, "Master Highway Plan for the Boston Metropolitan Area", prepared for the Department of Public Works by C. A. Maguire & Associates, J. E. Greiner Company and De Leuw, Cather & Company. Such a highway would connect the central core communities through

which it passes, serve as a collector for the radial highways and arterial streets approaching the heart of the Metropolitan Area and carry traffic around the congested central area.

The importance of the Inner Belt Highway was further recognized in 1958 when it was included in the National Interstate and Defense Highway System established under the provisions of the Federal Aid Highway Act of 1956.

In 1962 a further study titled, "Inner Belt and Expressway System, Boston Metropolitan Area" was submitted to the Department of Public Works by Hayden, Harding & Buchanan, Inc. and C. A. Maguire & Associates. In this report the summary of conclusions and recommendations contains the following:

> "This study reaffirms the validity of the Inner Belt and Radial Expressway concept and the urgency for early completion of the Expressway System."

The entire Metropolitan Boston Expressway System is based on a concept of a system of radial express

highways terminating at the circumferential Inner Belt Expressway. In the 1962 Report, it was again recommended that the Inner Belt "function as an interconnector between the several radials and as a collector-distributor for traffic having its destination or origin within the Central Core Area", further demonstrating the need for the Inner Belt Highway.

A socio-economic analysis was made of all communities in the Metropolitan area affected by the Inner Belt and Expressway System for inclusion in the 1962 "Inner Belt and Expressway System, Boston Metropolitan Area" Report. This analysis indicated that the construction of the expressway would materially stimulate the economic growth of Cambridge by the creation of 27,400 additional jobs, representing an increase of 31%.

All transportation planning conducted in the area for more than 20 years has conclusively proven the community need and value for the Inner Belt Route in its entirety as an essential part of the National Interstate Highway System for the Boston Metropolitan Area.

On several occasions during the past year various groups have advanced the claim that Inner Belt planning has been based on obsolete and inaccurate traffic data. While it is true that the 1948 and 1962

Metropolitan Boston studies were predicated on traffic counts made in 1946, the latest planning reflects up-to-date traffic data.

In 1962 the Eastern Massachusetts Regional Planning Project, in conjunction with Wilbur Smith and Associates of New Haven, Connecticut, undertook a comprehensive traffic study of the greater Boston Metropolitan Area. All current Inner Belt proposed plans, including the Cambridge Committee Alignment, are predicated on traffic assignments resulting from this current study.

As a result of this continuing study, the traffic demand on that portion of the proposed Inner Belt in the Cambridge area is conservatively estimated to be in the neighborhood of 100,000 vehicles per day by 1990. This analysis recognizes the existence of the traffic service provided by the Massachusetts Turnpike Extension and demonstrates the need for an eight lane expressway through the Cambridge area. This traffic demand will still exist even if the proposed expressway is not constructed.

An expressway such as the Inner Belt will carry three times the number of vehicles per lane per hour as a signalized arterial street. It will carry

this traffic more safely, more conveniently, more economically and faster.

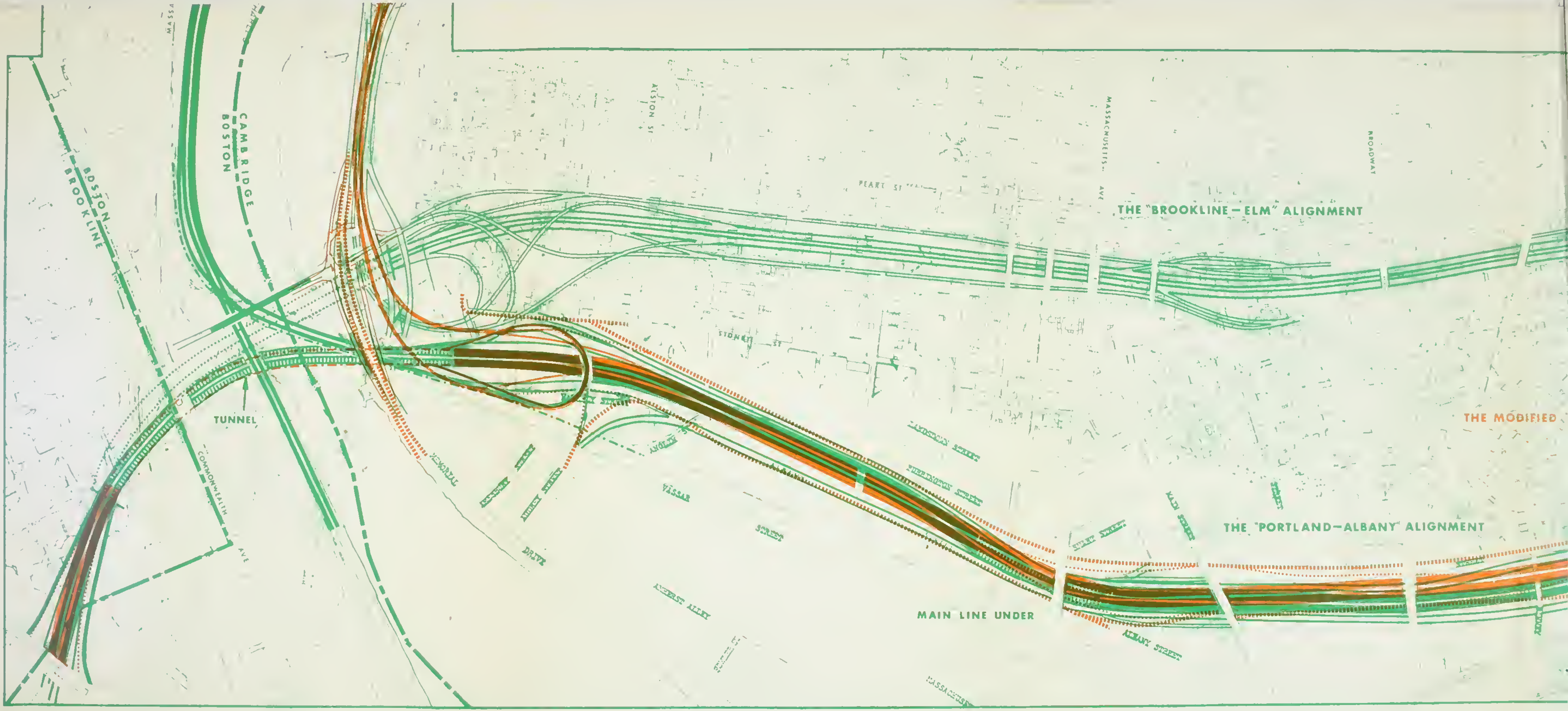
II. DESCRIPTION OF ROUTE

The horizontal and vertical alignment of the proposed Cambridge Committee plan is shown in Exhibits 2 and 3.

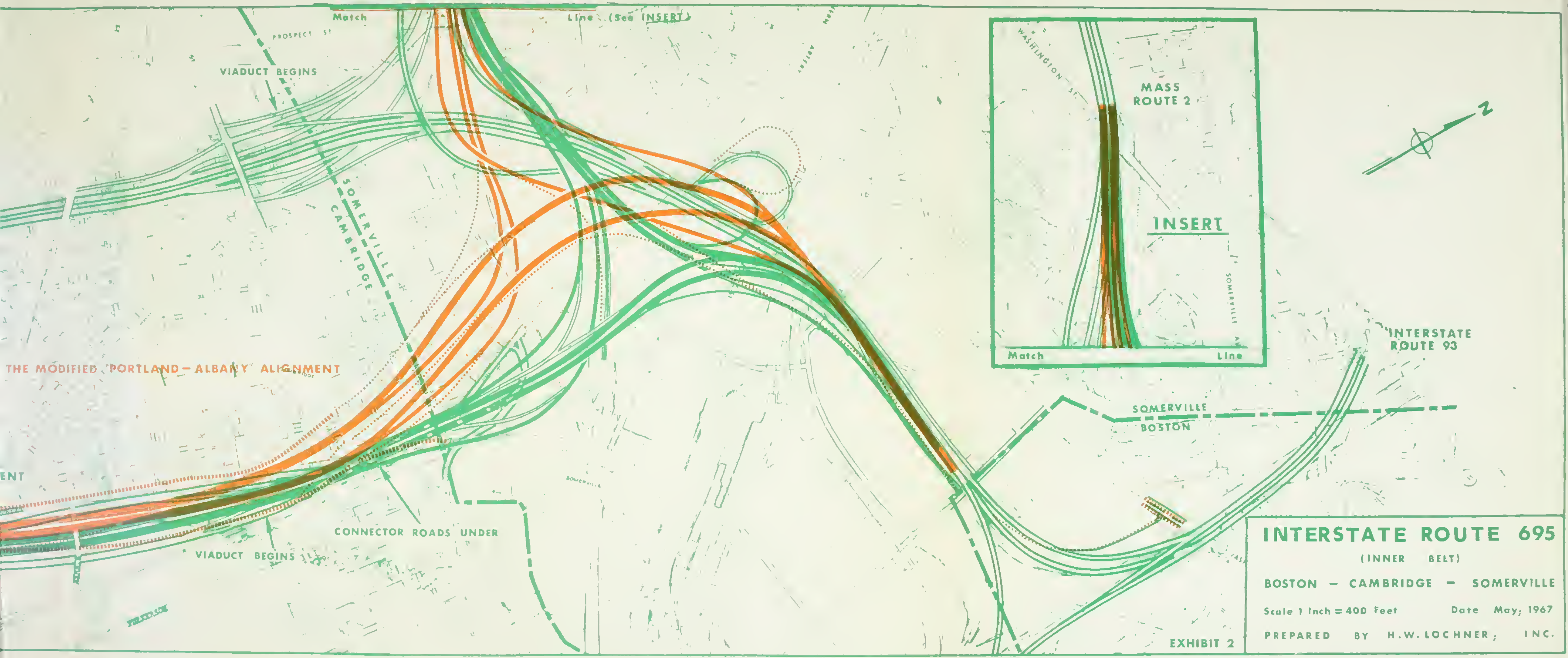
Generally described, the Committee's Alignment departs from the previously selected line at a point immediately north of Beacon Street in Brookline, curves to the east of the Brookline-Elm Route, passes under the Massachusetts Turnpike Extension, the Boston University campus and the Charles River via tunnel, and emerges from the tunnel on the Cambridge side of the River generally parallel to and westerly of Albany Street.

The connection to the Massachusetts Turnpike Extension is accomplished by interchanging the Inner Belt - Turnpike Connector traffic on the Cambridge side of the Charles River, carrying the traffic across the River on a new structure, mixing it with present Soldiers Field Road traffic for a distance of approximately one-quarter of a mile, then, near River Street, providing connecting roadways between Soldiers Field Road and the Allston Interchange of the Massachusetts Turnpike Extension.

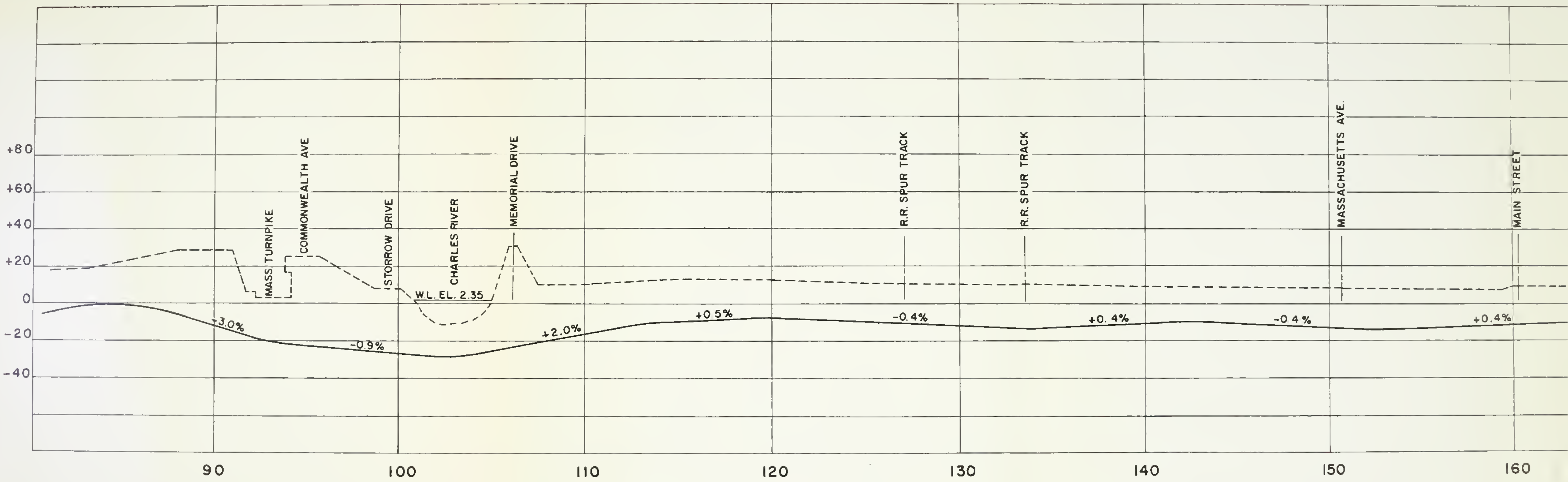
Continuing northerly on the Inner Belt from the Turnpike Connector Interchange and running

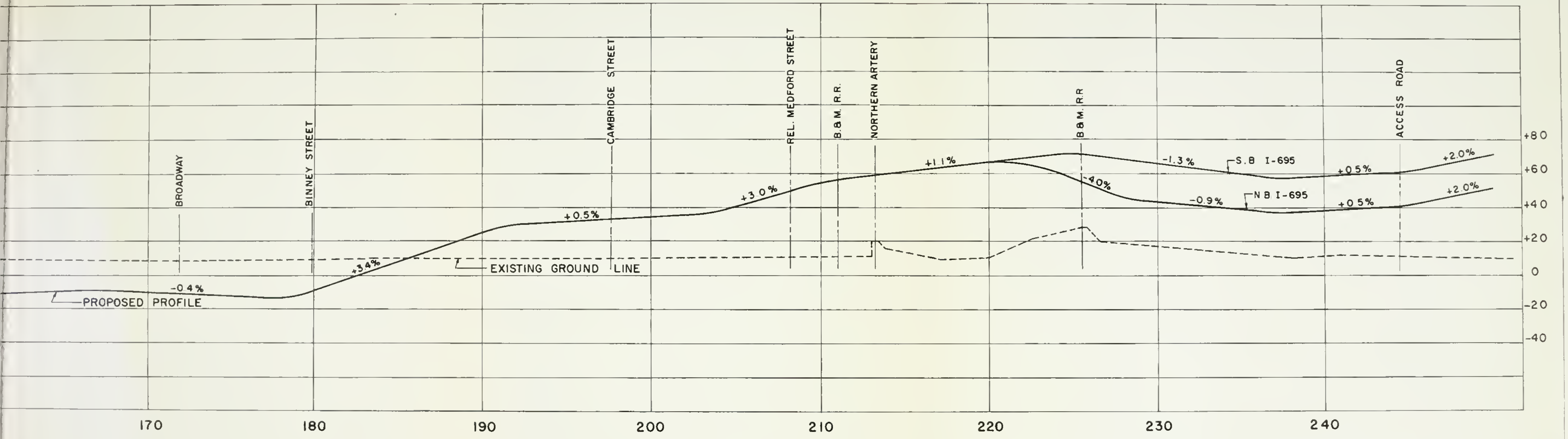


BOSTON
BROOKLINE
CAMBRIDGE
BOSTON
TUNNEL
COMMONWEALTH AVE
MEMORIAL DRIVE
VASSAR STREET
AMHERST ALLEY
ALSTON ST
PEARL ST
STONE ST
MASSACHUSETTS AVE
BROADWAY
ALBANY STREET
THE "BROOKLINE–ELM" ALIGNMENT
THE "PORTLAND–ALBANY" ALIGNMENT
THE MODIFIED
MAIN LINE UNDER



Match Line (See INSERT)
PROSPECT ST
VIADUCT BEGINS
SOMERVILLE
CAMBRIDGE
WASHINGTON ST
MASS
ROUTE 2
INSERT
SOMERVILLE
Match Line
INTERSTATE
ROUTE 93
SOMERVILLE
BOSTON
THE MODIFIED PORTLAND – ALBANY ALIGNMENT
ENT
CONNECTOR ROADS UNDER
VIADUCT BEGINS
EXHIBIT 2
INTERSTATE ROUTE 695
(INNER BELT)
BOSTON – CAMBRIDGE – SOMERVILLE
Scale 1 Inch = 400 Feet
Date May, 1967
PREPARED BY H.W. LOCHNER, INC.


+80
+60
+40
+20
0
-20
-40
90
100
110
120
130
140
150
160
MASS. TURNPIKE
COMMONWEALTH AVE
STORROW DRIVE
CHARLES RIVER
MEMORIAL DRIVE
R.R. SPUR TRACK
R.R. SPUR TRACK
MASSACHUSETTS AVE.
MAIN STREET
W.L. EL. 2.35
-3.0%
-0.9%
+2.0%
+0.5%
-0.4%
+0.4%
-0.4%
+0.4%



INNER BELT PROFILE
CAMBRIDGE COMMITTEE ALIGNMENT
PORTLAND-ALBANY ROUTE

SCALES: HOR. 1" = 400'
VERT. 1" 40'

MAY, 1967

H W LOCHNER, INC.

parallel to Albany Street, the Cambridge Committee has narrowed the corridor in an attempt to miss the Massachusetts Institute of Technology Buildings fronting on Albany Street (Instrumentation Laboratory, Nuclear Reactor and National Magnet Laboratory) and the main New England Confectionery Company Building directly opposite from the M.I.T. facilities.

Beyond Massachusetts Avenue the route curves to the left and becomes generally parallel to Portland Street. It crosses a portion of the Washington Elms housing area, severs a significant portion of the Technology Square development and passes directly through the manufacturing facilities of American Biltrite Rubber Company (Boston Woven Hose and Rubber Division).

Throughout the section of the Inner Belt up to the American Biltrite Plant, the Committee has proposed a depressed highway. However, in the vicinity of the American Biltrite facilities the Expressway becomes elevated and passes over Cambridge Street as it enters the Route 2 Interchange. Continuing on, the Inner Belt passes through the Somerville Incinerator Plant and the facilities of the Boston Edison Company finally tying into the present Inner Belt alignment immediately adjacent to the westerly boundary of the Industrial Park in Somerville.

It is noteworthy that the corridor embraced by the Committee's plan (Portland-Albany) has previously undergone extensive and detailed studies. One such study titled, Basic Design Report, Inner Belt Expressway, Cambridge and Somerville", was made by Goodkind & O'Dea, Inc. for the Department in 1965 and another was developed by Barton-Aschman Associates, Inc. for the City of Cambridge in 1966 and presented in their Report, "Alternate Alignments for the Inner Belt through the City of Cambridge, Massachusetts". The Barton-Aschman study was predicated on a plan suggested by the Committee. Both of these alternates, as well as the others that had been developed at that time, were analyzed in the "Summary Report, Boston Metropolitan Inner Belt Highway, Cambridge Section" prepared by H. W. Lochner, Inc. and referred to above.

III. ANALYSIS OF CAMBRIDGE COMMITTEE ALIGNMENT

As noted in the description of the route, the Committee's alignment follows essentially the same corridor as the Albany D line developed by Goodkind & O'Dea, Inc. in the Basic Design Report and the Portland-Albany line developed by Barton-Aschman Associates for the City of Cambridge. In both of these studies, it was concluded that a line in the Portland-Albany corridor warranted the development of detailed study plans. However, in both cases, after a careful evaluation, a line in different corridors was finally recommended. In any event, the possibility of an alignment in the Portland-Albany corridor was demonstrated and the line developed by the Committee warrants serious consideration and study.

The Committee, in the development of this line, attempted to minimize the negative effects on the residential, industrial and institutional areas of Cambridge. By using an extremely narrow and curved corridor, the Committee was successful in minimizing property damage in Cambridge, but, in its eagerness to protect residences, it overlooked the main principles of sound highway design practices - safe design and efficient traffic service for the thru and local movements without serious disruption of existing traffic patterns. The

Committee's design adheres to minimum design standards only when it is conveniently possible to do so; in an attempt to keep it out of Cambridge, the Massachusetts Turnpike Connector is made long and indirect; local arteries will be overtaxed by the closing of all secondary cross streets and the addition of the ramp traffic; etc.

The design deficiencies, taken one by one, are not strong enough to disqualify the line. However, throughout, numerous weaknesses are apparent. The alignment analysis lists and describes these weaknesses and, wherever possible, suggests ways to eliminate them without affecting the general Inner Belt corridor. Specific recommendations are made at the end of each section. These result from the study of the particular aspects of the design and should not be considered as final solutions for the Committee's total alignment.

Geometric Design

The geometrics of the Inner Belt through Cambridge, as proposed by the Citizens' Committee, are not compatible to the other sections of the Inner Belt.

In the basic design, all of the Inner Belt, including the Brookline-Elm alternate through

Cambridge, is designed with the maximum horizontal curvature limited to a radius of 1400', except for the one restricted location in the I-93 interchange area where a short section of 900' radius curve is used. Proper horizontal transition curves are applied throughout.

The Committee's alignment for the Inner Belt roadways uses the absolute minimum 830' radius curvature, ignores the Department's requirements for horizontal curve transitions and, with its short tangent sections, it is inadequate for proper superelevation transitions at curve reversals or broken-back curve locations. Such an alignment will have operating characteristics substantially different from those expected for the other sections of the Inner Belt, and a noticeable reduction in the over-all expressway capacity is unavoidable.

In general, ramps have been designed to the absolute minimum 25 m.p.h. standards, while in the development of the profiles, maximum 6% grades were used as a rule rather than as an exception. At restricted locations, pavement widths arbitrarily have been reduced by eliminating shoulders to provide the required minimum clearances from the controlling right-of-way locations to the structure edges.

Ramp entrance and exit terminal design

is inconsistent and, at many locations, the Department's or A.A.S.H.O.'s minimum criteria are not met.

Even though most of Cambridge's cross streets will be severed by the expressway, the Committee does not give any indication that improvements (widening, addition of turning lanes, etc.) will be required to the streets remaining open.

Many other specific alignment deficiencies are also apparent and they have been listed in the commentary that follows. The discussion has been subdivided into three distinct sections:

A. Charles River crossing and Turnpike connection.

B. Inner Belt through Cambridge.

C. Connection to Route 2 and I-695 in Somerville.

Comments on minor details have been omitted and only the more important design deficiencies are listed.

A. Charles River Crossing and Turnpike Connection

I-695 - Beacon Street, Brookline to Erie Street

Alignment controls for this section of I-695 are Boston University and the approved Inner Belt line through the Fenway south of the river and Albany Street and Fort Washington north of the river. To meet the control requirements the Committee has used a series of undesirable, unequal length horizontal compound curves.

1. The 1000' radius in the tunnel allows for 50 m.p.h. operation in the northbound lanes. For the southbound roadway, however, the inside face of the tunnel wall has to be offset 9' from the left lane edge to meet the 350' minimum horizontal sight distance requirement.

2. The transitional compound curves are of uneven lengths and numerous driver adjustments will be required to negotiate them.

3. The 12,000' radius curve just north of the tunnel portal does not eliminate the broken-back curve effect and is an undesirable design feature.

Interchange North of Memorial Drive

1. The 185' radius used for the loop ramps

restricts speed to 25 m.p.h. and requires structure widening of 4' on the left to provide the required minimum 160' sight distance.

2. The exit terminal to Ramps B-2 and B-3 is located in the tunnel which will require adjustments in the tunnel design to permit proper signing.

3. The distances between the successive exits and entrances for Ramps B-6 and B-1 and the S.B. Frontage Road and Ramp B-1 do not meet minimum A.A.S.H.O. requirements.

4. Ramp profiles are designed with maximum grades and minimum length vertical curves and have a "roller-coaster" appearance.

5. Ramp B-6 encroaches into Fort Washington and eliminates access from the Albany Street side of the park.

<u>Connector to Massachusetts Turnpike</u>

1. The Committee's proposal to utilize a section of Soldiers Field Road for the turnpike connection is unacceptable to the Metropolitan District Commission. Soldiers Field Road is

presently a part of the Boston Metropolitan System of Parkways. The imposition of mixed traffic on this roadway would be inconsistent with the parkway concept. Further, present traffic volumes on this facility preclude the efficient handling of any additional traffic.

2. Encroachments into Charles River channel extending up to 75' are required for the Soldiers Field Road - Turnpike Connector pavements beginning at the Boston University Bridge and extending west and north for a distance of 3200'±.

   A similar encroachment was proposed by the Massachusetts Turnpike Authority during the development of the Turnpike Extension a few years ago. The Metropolitan District Commission opposed this move and in a subsequent Supreme Court case, a decision was rendered prohibiting the Turnpike Authority from this proposal.

3. Reconstruction of the Boston University Bridge is required to allow the connector roadways to pass under. This work is to be performed under

traffic and it is inconceivable how adequate and reasonably economical detour facitilites can be provided in this area.

B. Inner Belt Through Cambridge

I-695 - Erie Street to Binney Street

1. The tangent distance between the 3200' and 1700' radius curve reversal south of Massachusetts Avenue is too short to effect an adequate superelevation transition.

2. Horizontal transition curves are required on both sides of the 1700' radius curve at Massachusetts Avenue.

3. The tangent distance between the 3300' and 3200' radius curves between Erie and Pacific Streets is too short to avoid designation as a broken-back curve (A.A.S.H.O. requires 1500' tangent length or the use of transitional curves).

4. The Expressway profile has been designed using the undesirable, absolute minimum 0.4% grade in the depressed section.

Local Access Ramps

1. Main Street Ramps

   a. Ramp F exit terminal is located under the support beams required for the frontage road cantilevered construction. Modifications to the expressway profile are required to provide for proper signing to this exit.

   b. Ramp H enters the expressway on the inside of a sharp mainline curve. The acceleration lane length should be increased to provide adequate sight distance for both ramp and expressway merging traffic.

   c. The combined intersections of the ramps and the frontage roads with Main Street are very undesirable. On the exiting roadways some turning movements have to be prohibited, while for the entrance conditions turning movements to wrong roadways are very likely.

   d. Ramp profiles are designed with maximum grades and minimum length vertical curves.

2. Binney Street Ramps

a. Ramps are located too close to the Route 2 Interchange and serious weaving conditions can be expected on the expressway.

b. Ramp profiles are designed with maximum grades and minimum curve lengths. In this area, ramp lengths can easily be increased effecting substantial geometric design improvements.

<u>Local Streets and Frontage Roads</u>

1. Albany Street - Northbound Frontage Road

a. The existing Albany Street width south of Massachusetts Avenue is inadequate for combined local and exiting expressway traffic.

b. Sidewalk provisions have not been included for the section between Massachusetts Avenue and Main Street. To provide for sidewalks the corridor width must be increased.

c. Connection to the truck service ramp at the Tech Square building north of Main

Street is possible only if the frontage road profile is designed with an extreme dip at this location.

2. Southbound Frontage Road

   a. North of Broadway existing Portland Street right-of-way should be utilized for frontage road purposes.

   b. Between Erie and Necco Streets the frontage road is located immediately east of existing Purrington Street. Under the Committee's proposal the ultimate use of that street would be limited to the railroad spur track only. This appears to be an unnecessary waste of land.

   c. Provisions for sidewalks between Main and Osborn Streets have not been made.

3. Cross Streets

   a. Cross street widening will probably be required at several locations due to the addition of Inner Belt ramp traffic and turning movements.

b. No provisions are made for vehicular or pedestrian cross movements across the Inner Belt between Memorial Drive and Massachusetts Avenue. Consequently, all facilities in this section of the city, including M.I.T. and Fort Washington, are isolated from the rest of Cambridge.

C. <u>Connection to Route 2 and I-695 in Somerville</u>

<u>I-695 - Binney Street to Somerville Industrial Park</u>

1. Horizontal alignment does not meet Massachusetts or A.A.S.H.O. requirements for 50 m.p.h. design speed as noted below:

    a. The 830' radius is an undesirable, absolute minimum for the design speed.

    b. Transition curves have not been used.

    c. Tangent distance between the 1500' and 830' radius curve reversal is too short to effect a proper superelevation transition.

    d. The 460' total length of the 1500' radius curve is too short for a deflection

of $17^{\circ}\pm$.

e. Viaduct widths have to be increased by 2' for the northbound roadway and by 8' for the southbound roadway on the inside of the 830' radius curves to provide the minimum 350' horizontal sight distance requirement.

2. Ramp and connecting roadway entrance and exit terminals do not meet the Department's or A.A.S.H.O. requirements.

   a. Inadequate merge and diverge lane lengths are provided for the two-lane connectors to Route 2.

   b. Connectors AW and AEW are merged into I-695 at the same location in violation of A.A.S.H.O. requirements. The lane merging distance is inadequate.

   c. The design of the Connector D exit from I-695 S.B. will result in a dangerous operating condition. Vehicles will be required to reverse travel direction from an 830' radius curve to the left directly into an 1100' radius curve to the right with no intermediate tangent

length to effect a proper superelevation transition.

3. In the development of the vertical alignment, minimum length vertical curves have been used throughout the Route 2 interchange, although, generally, 50 m.p.h. design criteria have been met.

   a. I-695 profile south of Route 2 interchange has an undesirable terraced appearance. Proceeding north from Binney Street a $3.4\%^{\pm}$ grade is used to come out of the "boat" section and to overcross Cambridge Street, then the grade is reduced to the minimum 0.5% for a distance of 1000' before going to the next 3.0% increment to overcross the Route 2 interchange roadways.

   b. The continuity of a depressed expressway through all of Cambridge is broken by overcrossing Cambridge Street. In the Brookline-Elm scheme this street is undercrossed by the Inner Belt.

<u>Route 2 and Connectors to I-695</u>

1. The horizontal alignment does not meet the requirements for 50 m.p.h. design.

   a. The tangent distance between the 1100' radius curve just north of the interchange and the 3400' radius curve beyond study limits is too short for proper superelevation transition.

   b. Transition curves are required on both ends of the 1100' radius curve.

   c. The connector from Route 2 to I-695 N.B. is split to avoid weaving on the interstate roadway. The reverse curve design is inadequate for the connector, and the over-all roadway design favors the smallest, exiting movement to the Industrial Park ramp.

   d. Connector B is not designed in accordance with the Department's minimum standards.

   e. Profiles for all connectors have undesirable "roller-coaster" characteristics. This feature is extremely obvious in the profile for Connectors AE and AEW - the roadway with the largest number of

consecutive points of driver decisions.

f. Roadway widths shown do not make provisions for full shoulders on the connector roadways.

2. Approximately 500' of the Connector B viaduct structure is located directly over existing Somerville Avenue and its intersection with the Northern Artery and Medford Street. This section is too long for a single span structure. Intermediate piers have to be located in the existing streets and extensive relocations of local arteries become unavoidable.

<u>Local Access Ramps</u>

1. Connections to Cambridge Street

   a. Ramps discharge to the frontage roads located under the expressway viaduct, where the visibility is considerably reduced by the overhead structure and its support columns. For safety and appearance, frontage roads should be located adjacent to, not under the viaduct structure.

b. Ramp SA is inadequately designed. The 500' reverse curves require a tangent distance between them to effect superelevation transitions; the entrance to Connector B does not have the required stopping sight distance and the profile grade is at the maximum + 6.0%.

c. Ramp SD exit from Connector C is on the left side of the roadway and on the high side of a superelevated section resulting in an extremely hazardous operating situation.

2. Connections to Northern Artery

a. Ramp SE is of inadequate width and its exit from Connector AE is substandard.

b. Ramp SE entrance to Connector D is located on a sharp curve immediately following a major split. The acceleration lane length should be increased to provide a safe merging condition.

3. Connections to Industrial Park Area

a. Exit Ramp SG is overdesigned. More

importance should be placed on the movement from Route 2 to I-695 N.B. instead of this ramp.

b. Entrance ramp from Washington Street is physically feasible, but at its entrance to I-695 the sight distance is inadequate. A long acceleration lane should be used to provide safe merging conditions.

Summary and Recommendations

The geometrics for the Inner Belt, as proposed by the Cambridge Committee, at most locations barely meet the absolute minimum design requirements. In several areas the design is totally inadequate and unacceptable. Specifically, it is recommended that:

1. The compound curve alignment used for the Charles River crossing should be improved to minimize the need for tunnel widening to provide the minimum horizontal sight distance.

2. The alignment of I-695 at Massachusetts Avenue should be improved by introducing the required horizontal transition curves.

3. The entire Inner Belt interchange with Route

2 should be redesigned to meet minimum design standards.

4. All ramp entrance and exit terminals should be checked for conformance to the design standards.

5. The absolute minimum 0.4% grades used for the I-695 profile in the "boat" section should be increased as much as possible to minimize the problems of draining the low pavement areas.

6. Ramp and connecting roadway profiles should be improved by the use of longer vertical curves and, wherever possible, flatter grades.

Traffic Service

A. Inner Belt

The Committee's proposed design makes adequate provisions for the interstate thru traffic movements at all locations, except the Route 2 interchange area where geometric modifications are required to meet minimum design criteria. In some areas, alignment restrictions and the close spacing of successive ramp entrances and exits on occasions will cause unstable flow conditions on the expressway. Over-all, however, the design of the

interstate roadways does meet the minimum A.A.S.H.O. requirements for restricted urban areas and the traffic service provisions are acceptable.

B. Massachusetts Turnpike Connector

The turnpike connector roadways are extremely long and indirect. Northbound interstate traffic from Boston and Brookline destined for the turnpike is required to cross Charles River into Cambridge, enter the loop connector roadway, recross Charles River and merge with Soldiers Field Road traffic before reaching the turnpike entrance ramp. The reverse movement retraces this path in the opposite direction.

For southbound vehicles the turnpike connection is not adverse and, except for the undesirable mixing of traffic at Soldiers Field Road and a somewhat longer length, it is comparable to the alternate along Memorial Drive.

As noted in the section on the geometric design, the proposed intermix of traffic on Soldiers Field Road is extremely undesirable and unacceptable to the Metropolitan District Commission. At present Soldiers Field Road is a parkway on which all truck traffic is excluded. This exclusion would have to be eliminated to

accommodate the turnpike-bound interstate traffic. Also, a new weaving section would be added resulting in additional vehicular friction on Soldiers Field Road - a facility that presently operates at its capacity and cannot accept any more traffic without possible operational breakdowns. Far superior is the turnpike connector along Memorial Drive and, for traffic service requirements, it is more desirable for either Inner Belt corridor.

C. Ramp Service for Destinations South of Cambridge

The location of the ramps at Main Street and at the terminals of the frontage roads west of Massachusetts Avenue severely restricts access to these ramps via streets other than Main Street or Massachusetts Avenue. Both of these streets are important local traffic carriers and provide the best direct connections from Cambridge to Boston. The addition of traffic from the interstate highway to these streets will reduce their thru capacity and create heavy congestion on the approaches to the Inner Belt.

Northbound interstate traffic destined for Cambridge and exiting at the ramp just north of Charles River to the Albany Street frontage road is held captive on this street all the way to Massachusetts Avenue (a

distance of 2900'). Abutting Albany Street are industrial facilities and M.I.T. research laboratories, all of which receive large truck shipments. It is possible that at times the entire Albany Street width will be blocked by trucks maneuvering into the loading dock areas. At such times the street and exit ramp traffic would be completely stopped. This is not acceptable for a facility serving interstate traffic. To provide proper traffic service it is required that additional cross streets be opened up (possibly Pacific Street) or the ramp location be moved to a point closer to Massachusetts Avenue. If the ramp is left at the location shown it is likely that the majority of Cambridge-bound traffic would exit through the Main Street ramp causing extreme capacity problems on that street.

The restrictions along Southbound Frontage Road west of Massachusetts Avenue are not as extreme. However, the distance from Massachusetts Avenue to the ramp entrance is excessive and, once again, it is advantageous for the expressway-bound traffic to use the Main Street entrance, thus complicating capacity problems on that street even more.

As designed, the ramps just north of the Charles River would receive little usage. Traffic using

them would be limited mainly to vehicles with destinations west of Massachusetts Avenue. They would serve as overflow facilities, but would not approach their capacity capabilities.

Ramps at Main Street, on the other hand, would be severely overtaxed. As designed, some of the turning movements at ramp and frontage road intersections with Main Street are prohibited. This causes traffic to circulate in a rotary-type pattern between Massachusetts Avenue, Main Street and Broadway. If all the streets and frontage roads would be one-way facilities, this pattern would not be objectionable. But since the three cross streets are major two-way traffic carriers, it is obvious that the capacity of the streets will be reduced when the ramp left-turn traffic is required to go through four signalized intersections instead of the normal two.

The undesirable intersections at Main Street would be eliminated by outletting the ramps into the frontage roads some distance before the intersection. Left turns could then be permitted and traffic could circulate in a more efficient manner. Of course, such change would require acquisition of additional property, but for traffic service purposes it is considered a necessity.

D. Ramp Service for Destinations North of Cambridge

Traffic for points north of Cambridge is served by ramps terminating at Binney and Cambridge Streets. Since between these two streets no other local connections are made, it is obvious that the ramps terminating at Cambridge Street serve only that street. All other traffic is distributed by the next set of ramps and serves Binney Street, Broadway, Main Street and Massachusetts Avenue.

This cannot be considered as a proportional traffic distribution. Obviously, the ramps terminating at Binney Street should either be moved closer to Main Street or eliminated completely. Traffic demand precludes choice of the second alternative, consequently, for better traffic service, ramps should be shifted southwest.

E. Route 2 Interchange

As discussed in the section on Geometric Design, this interchange does not meet minimum design standards. For traffic service, however, connections have been provided for all movements and, if the geometrics of the interchange can be revised to meet acceptable design standards, traffic service provisions would be adequate.

F. Local Streets

Except for Binney Street, only the major thoroughfares (Memorial Drive, Massachusetts Avenue, Main Street, Broadway and Cambridge Street) are kept open across the Inner Belt. All expressway ramp traffic is fed via the frontage roads to these local thru traffic carriers. No provisions whatever are made for traffic distribution through secondary streets at times of over-congestion on the main arteries. This is especially true for the northbound frontage road south of Massachusetts Avenue where the proximity of industries and railroad tracks precludes possible connections to other local streets.

In the vicinity of the Inner Belt the main streets would still carry the majority of the Boston - Cambridge traffic using Harvard and Longfellow Bridges, local Cambridge traffic originating at M.I.T., Tech Square and the proposed NASA center would use them, and, the Committee's design proposes to place all ramp traffic there also. Without some safety-valve secondary street distribution provisions these streets can be expected to have traffic capacity breakdowns and very poor operating characteristics, and it is essential that additional crossings be provided.

An additional bridge and street connection across the Inner Belt to Vassar Street in the vicinity of Pacific Street is considered a necessity not only for traffic distribution purposes, but also to provide access for emergency vehicles to properties fronting Albany Street west of Massachusetts Avenue.

Another location requiring a bridge crossing is Hampshire Street. This street and Webster Avenue, which radiates from it just north of the Inner Belt, are continuous through Cambridge and Somerville and their direct connection to Broadway and Boston should not be severed by the Inner Belt.

Summary and Recommendations

The Committee's design makes adequate provisions for interstate thru traffic movements. Some of the ramps and local roadways, however, do not provide adequate traffic service and the following revisions are recommended:

1. The turnpike connector should be designed along Memorial Drive to provide a more direct connection and to avoid using a corridor which is unacceptable to the Metropolitan District Commission.

2. Main Street ramps should be merged with the frontage roads south of Main Street to eliminate the undesirable ramp-frontage road intersections with Main Street.

3. Binney Street ramps should be moved south to provide a more even traffic distribution on the successive ramps in that area.

4. Cross street bridges should be added at Pacific and Hampshire Streets to provide better ramp traffic distribution and minimize disruption of existing traffic patterns.

Drainage and Utilities

Storm and sanitary sewers in Massachusetts Avenue, Main Street, Broadway, Hampshire Street and Binney Street have to be siphoned under the depressed expressway. Other utility lines can be suspended under the cross road structures.

Existing sewer lines in Portland and Albany Streets require relocations in the vicinity of Tech Square and Massachusetts Avenue. In those areas, the expressway corridor is extremely narrow and all existing utility lines will be disturbed. In Albany Street

extensive utility relocations may be required since the proposed 15' minimum space between the building lines and the face of depressed expressway wall appears to be too narrow for replacement of all existing utilities. Alternate route locations will have to be found.

Two pumping stations are required to drain the expressway storm water. One can be located in the vicinity of Broadway with the outflow going to Broad Canal. For the second pumping station it is difficult to find an adequate location. Ideally, it should be located near the expressway profile low point at Massachusetts Avenue. However, in this area the expressway corridor is severely restricted and space for a pumping station is not available. An alternate location may be south of Pacific Street with the outflow going across M.I.T. athletic fields and Fowler Street to the Charles River, however, a detailed study is required before a final determination can be made.

M.B.T.A. Subway Relocation

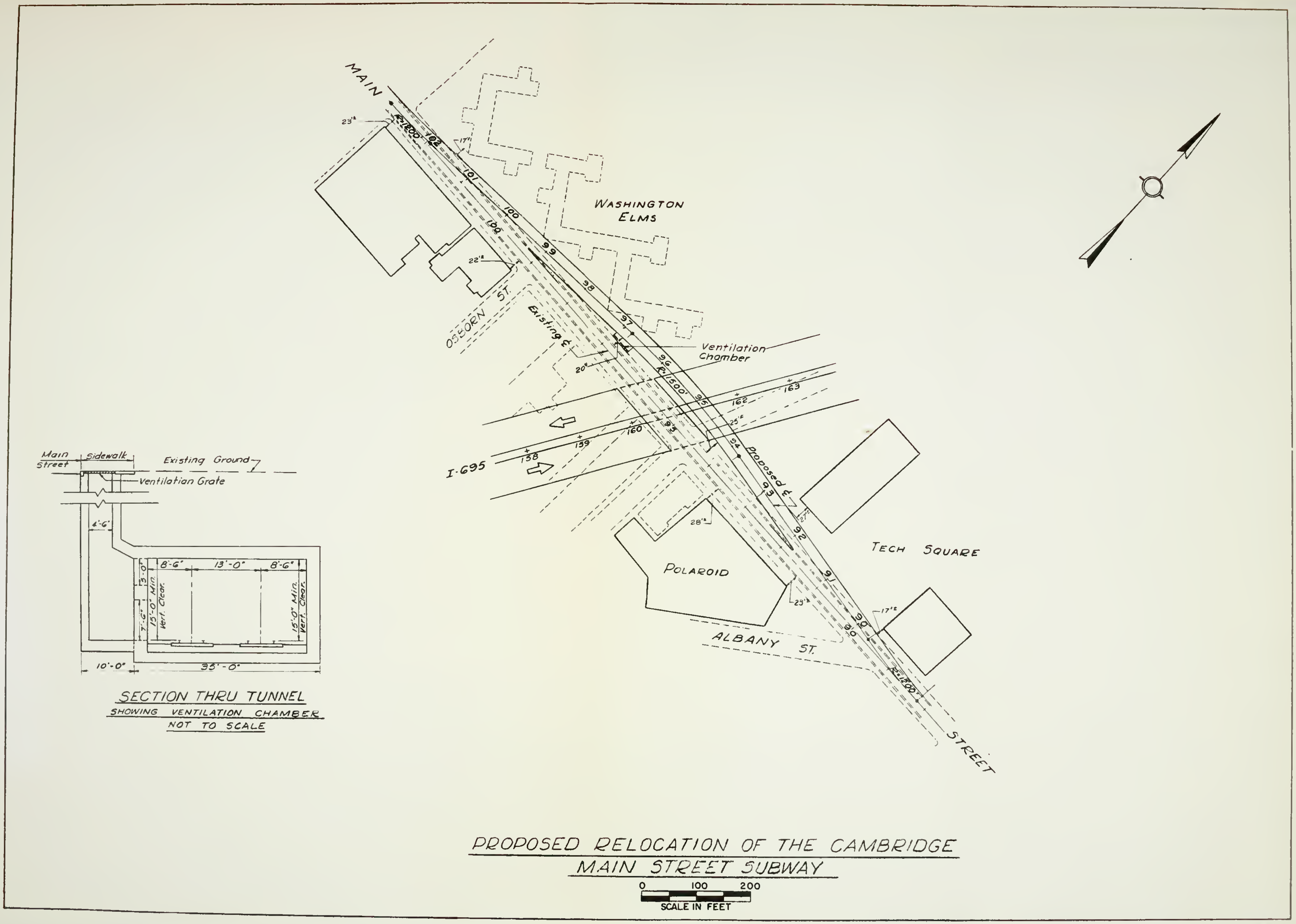
The Main Street M.B.T.A. Subway between Windsor and Albany Streets will have to be lowered to accommodate I-695 which is depressed in this area. The service on this line cannot be interrupted and,

consequently, the lowering of the subway can be accomplished only by a relocation of the tunnel.

The Cambridge Committee indicated that the relocation could be accomplished by constructing two tunnels, one on either side of the existing tunnel. Upon investigation, it was determined that the tunnel on the south side of Main Street could not be constructed without encroaching upon the Polariod Corporation's building between Albany and Portland Streets.

The less damaging alternative, a two track single tunnel relocated on the north side of Main Street was investigated as shown in Exhibit 4. Using M.B.T.A. Design Standards the vertical alignment of this scheme would allow a speed of forty-five (45) miles per hour but the horizontal alignment restrictions reduce the speed to approximately forty-two (42) miles per hour.

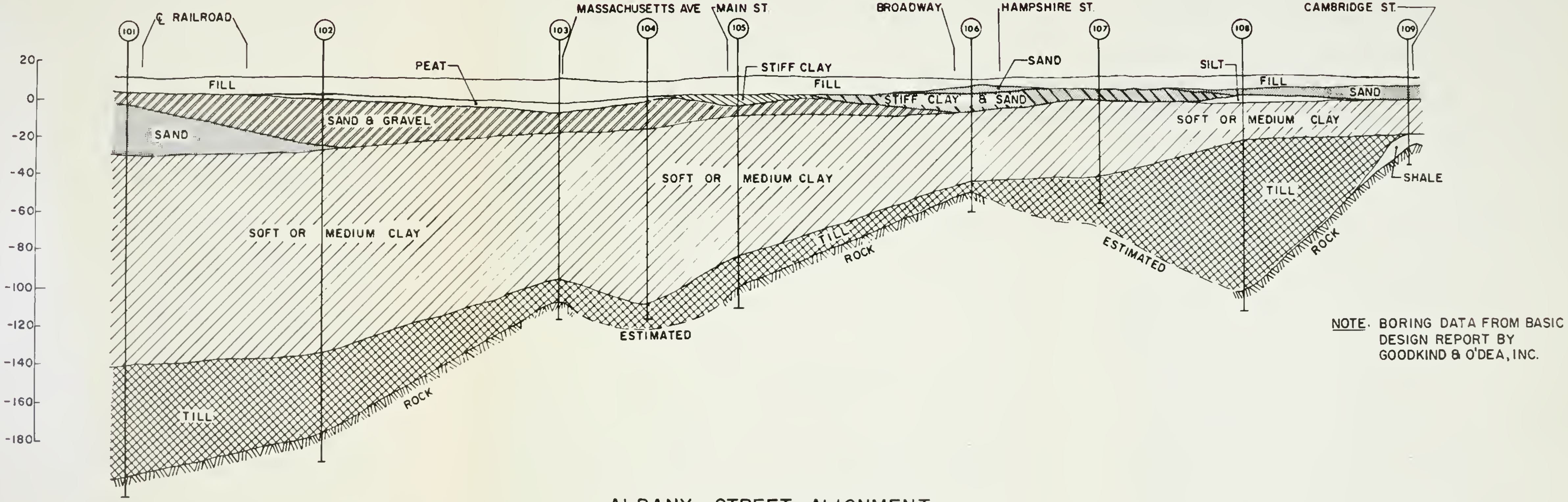
The alignment of the single tunnel scheme necessitates a partial taking and alteration of several units of the Washington Elms apartment complex. Also, an easement is required through the Tech Square complex and two buildings have to be underpinned to prevent possible settlement damages during construction.



PROPOSED RELOCATION OF THE CAMBRIDGE MAIN STREET SUBWAY

0 100 200
SCALE IN FEET

EXHIBIT 4



ALBANY STREET ALIGNMENT

HOR: 200' 0' 200' 400' 600'
VER: 20' 0' 20' 40' 60'
SCALE IN FEET

INTERSTATE ROUTE 695
CAMBRIDGE
ALBANY STREET ALIGNMENT
SOILS PROFILE

MAY, 1967 H.W. LOCHNER, INC.

EXHIBIT 5

IV. SUBSURFACE CONDITIONS

The study of subsurface conditions along the Committee's Portland-Albany Route has shown that the deep excavation required for the proposed depressed section poses major construction problems. A Soils Report, prepared by James P. Collins & Associates, Inc., is included in the Appendix of this Report and it presents in detail the many ramifications of the critical soils problems encountered in the study of this route. It is evident from the report that conventional methods cannot be applied for the construction of this highway section.

At the request of the Department of Public Works, Mr. H. A. Mohr, Soils and Foundations Consulting Engineer, reviewed the proposed Cambridge Committee alignment relative to the problem of constructing the depressed portion of the plan, primarily in the Massachusetts Institute of Technology - Technology Square area. In presenting his findings to the Department, Mr. Mohr has indicated that, while this depressed highway can be built in this location, conventional construction practices cannot be used.

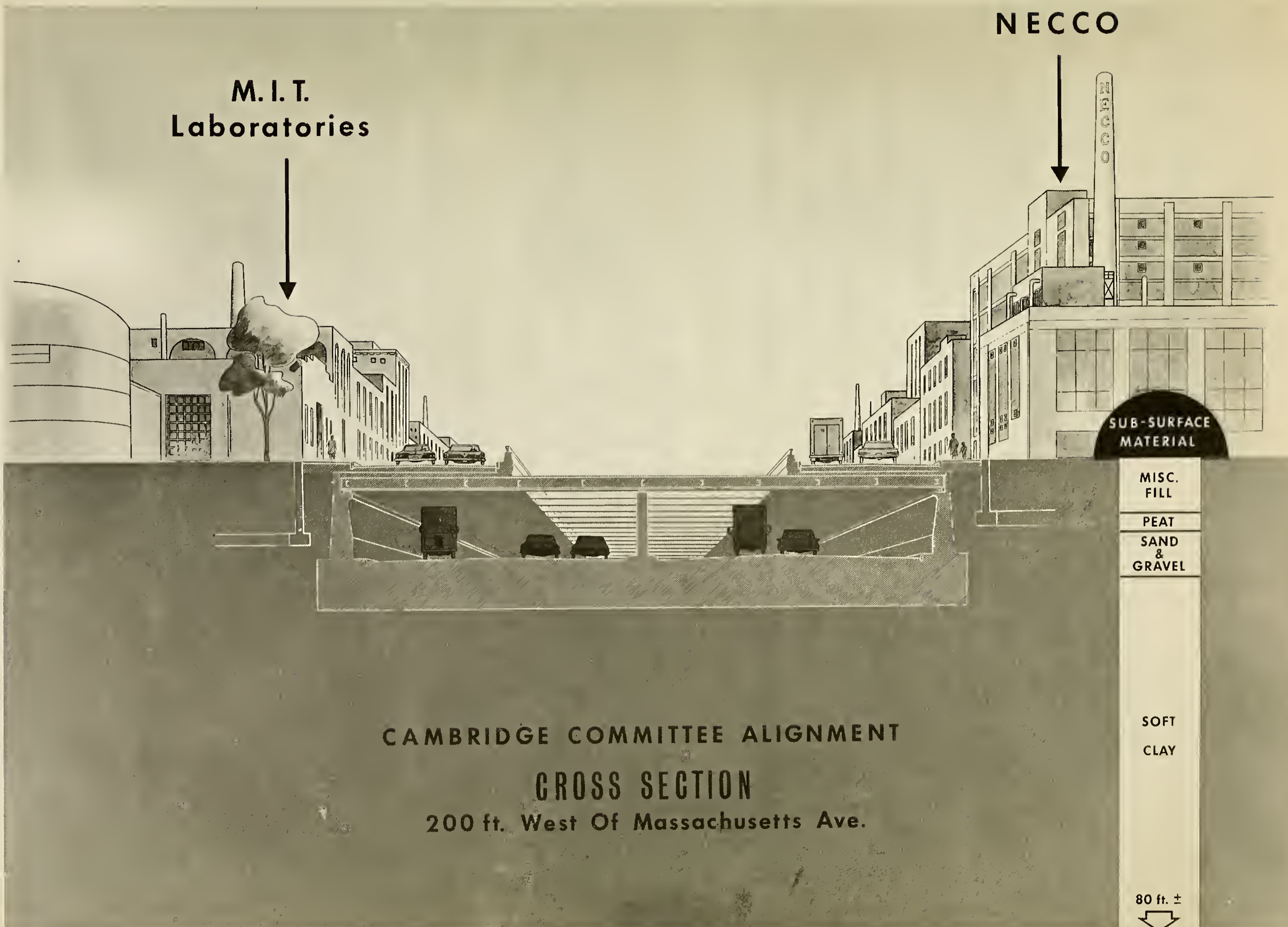
Other soils and foundations specialists familiar with the subsurface condition in this area have presented similar findings.

In general, the profile of the I-695 roadway will be approximately 25 feet below ground surface at elevation -15, while the existing water table is approximately at elevation 0 throughout the length of the Albany Street Alignment. Because of this relatively high water table, the uplifting effect on the roadway caused by the hydrostatic pressure will require that a concrete slab up to 12 feet thick be provided to resist this force. As a result, an initial total depth of excavation ranging from 35 to 40 feet will be required.

Obviously, extraordinary measures will be required to: 1) prevent shear failures or eruption of the floor of the excavation, 2) properly control ground water levels to prevent settlement damages to surrounding buildings (the existing foundations of many buildings immediately adjacent to the excavation will require underpinning), and 3) control the lateral movement of the vertical walls of the excavation.

Several possible methods of constructing the highway under these conditions are discussed in the attached "Soils Report". Other methods can undoubtedly be suggested. However, it must be recognized that no matter which method is developed, the cost of construction will be greater for this section than for a roadway built

with conventional methods. Further, the Department must exercise extreme caution in the selection of the route location to insure against potential damage to adjacent major research and manufacturing facilities in areas such as the restricted corridor near Massachusetts Avenue.


M.I.T.
Laboratories
NECCO
NECCO
SUB-SURFACE MATERIAL
MISC. FILL
PEAT
SAND & GRAVEL
SOFT CLAY
80 ft. ±
CAMBRIDGE COMMITTEE ALIGNMENT
CROSS SECTION
200 ft. West Of Massachusetts Ave.

V. URBAN CONSIDERATIONS

Because of the long term effects - as well as the immediate impact - of the construction of a major highway on a community such as Cambridge, it was concluded that, in presenting the urban aspects of the project, a locally based organization that has been a long time resident of the community and has shared in its growth, should develop the information on urban considerations. Accordingly, in response to our request, The Architects Collaborative, Inc. has provided the material for this section.

The Portland-Albany Alignment developed by the Cambridge Committee, beyond the fact that it achieves fewer residential takings, is detrimental to the City of Cambridge in every other aspect of urban existance.

In addition to the geometric design deficiencies, as well as weaknesses in traffic service, discussed in Section III, several other considerations merit additional discussion.

Design Aspects

1. Air Rights Construction

The most promising way to use air rights is to construct three to four story buildings over the depressed highway, utilizing the weight of the buildings to hold down the depressed roadway (in liew of building 12 foot thick concrete slabs at the bottom of the boat sections). In the case of low and middle income air rights housing, Federal programs would pay for two-thirds of the construction cost of foundations and platforms with the remaining one-third coming from local sources. Thus low and middle income housing seems to be economically most feasible and socially the most desirable type of construction over the depressed highway.

Unfortunately, the design of the Committee's Alignment is of such nature that where it is depressed it passes through an industrial area, thus unsuitable for residential construction, and where it is adjacent to residential areas it is elevated, thus unsuitable for any type of air rights construction.

There is some possibility for commercial air rights construction at the Massachusetts

Avenue crossing of the Inner Belt. However, this is generally too far away from the Central Square business area to exercise any appreciable influence over it and is in the section that will soon become institutional. Further, unlike low and middle income housing development where Public funds can be applied, all foundation costs must be borne by the developer of commercial buildings. On this basis adjoining land can probably be purchased at a lower cost than for the development of foundations and platforms over the highway.

2. Undesirable Influences

The portion of the highway along the Wellington-Harrington renewal project changes from a depressed roadway at Binney Street to elevated at Cambridge Street. The elevated highway at this location will produce an undesirable psychological and visual influence on the newly planned residential area. The noise caused by climbing truck traffic on the expressway will have a further detrimental effect on the new community.

In the vicinity of Massachusetts Avenue, the

frontage roads are carried partially over the expressway on beams spanning the highway to reduce the width of the corridor at this location. Because of this partial covering of the highway, uneven exposure to the sun will occur. This will result in unusual daytime lighting effects, and potentially dangerous wintertime operating conditions where icy and dry lanes (caused by unequal exposure to the sun) run parallel to each other.

Future Community Growth

In proposing the Portland-Albany Alignment the Cambridge Committee has largely ignored the future economic growth of the City. It is painfully evident that the City of Cambridge, which has just gone through the sacrifice of displacing businesses to accommodate the proposed facilities of the National Aeronautics and Space Agency, must again suffer the loss of further major commercial and industrial concerns because of this proposed highway through the industrial area of the City. The further erosion of the City's tax base would be extremely significant.

A major developer has negotiated with the City of Cambridge for a large commercial development known as Technology Square. Approximately fifty per cent of the planned development has already been completed with the remaining sections to be started in the immediate future. However, the Committee's plan will require the acquisition of a significant portion of the Tech Square area which will seriously impair the optimum future development of this desirable property. The present development forms a significant portion of the City's tax base but, more importantly, the ultimate development will have a major impact on the tax base.

The American Biltrite Company, a major employer in Cambridge, is presently advancing plans to expand the operations at this site. However, the Committee's plan will not only negate this expansion, but will put this factory out of business.

Other major companies that will be either put out of business or seriously affected include: the Polariod Corporation, Massachusetts Lumber

Company, Atlantic Paper Box Company, Robert Fawcett and Son Co., Inc., Fay Distributing Company, Delta Tire Company, New England Confectionery Company and the Massachusetts Institute of Technology. All of these firms and M.I.T. have written to the Department voicing their opposition to this alignment.

Conservation of Parks and Natural Resources

The Committee's proposed Turnpike Connector occupies the bank of the Charles River for a distance of some 3200 feet and projects into the river up to 75 feet throughout this length. Every effort should be made to preserve the existing bank along the Charles River Basin rather than impose a highway, or for that matter, any type of construction on its banks.

The site of the Fort Washington Park Memorial is, under the Committee's plan, rendered practically inaccessible to anyone wishing to visit it. It is bounded on the east side by the railroad, on the north side by industrial development and now, on the only two sides from which access could be gained, by ramps.

VI. CONSTRUCTION AND RIGHT-OF-WAY COSTS

The summary of construction and right of way costs are shown in Exhibit 8 while family and job displacements are tabulated in Exhibit 9. Both of these Exhibits are presented on the same sheet.

The right-of-way cost estimates were developed by the Department of Public Works, Bureau of Right-of-Way and the construction cost estimates were made by Goodkind & O'Dea, Inc. and Sverdrup & Parcel and Associates, Inc. Since the construction cost estimates for the various schemes previously considered in the Boston-Cambridge-Somerville area had been prepared by these Firms, they were requested to prepare these estimates to insure continuity of techniques and uniformity of unit prices.

In preparing the estimate of costs for the Committee's proposed plan, Goodkind & O'Dea, Inc. reappraised the estimate of cost for the Albany "D" Alignment and found that, in light of more precise subsurface information, the cost estimate shown in the tabulation has increased from the previous estimate. In the Basic Design Report phase Albany "D" Alignment had been rejected, for other reasons, before a more extensive investigation of the existing soils conditions could be started, and the

estimates in the Basic Design Report could not reflect the costs due to the extraordinary construction methods required for this alignment.

The construction costs for the Brookline-Elm Alignment were also reviewed at this time and they were found to be satisfactory.

The displacement estimates (families and jobs) tabulated in Exhibit 9 were prepared by the Department of Public Works. In preparing these statistics the following geographical limits were used:

> Cambridge - From the Charles River to the Cambridge - Somerville City Line.
>
> Somerville - From the Cambridge - Somerville City Line to Joy Street on I-695 and to Washington Street on Route 2.

SUMMARY OF ESTIMATED COSTS
Beacon Street to Joy Street

SCHEME	CONSTRUCTION	RIGHT-OF-WAY	TOTAL
PORTLAND-ALBANY By Cambridge Committee	$134,089,000	$18,600,000	$152,689,000
PORTLAND-ALBANY Modified Alignment	$134,178,000	$28,700,000	$162,878,000
BROOKLINE-ELM	$101,898,000	$23,900,000	$125,798,000

SUMMARY OF ESTIMATED DISPLACEMENTS
Charles River to Joy Street

PORTLAND-ALBANY By Cambridge Committee

CITY	FAMILIES	JOBS	BUSINESSES
CAMBRIDGE	130 (150)	3685 (2600)	69
SOMERVILLE	136 (50)	833 (225)	56
TOTAL	266 (200)	4518 (2825)	125

Figures in parenthesis estimated by Cambridge Committee

PORTLAND-ALBANY Modified Alignment

CITY	FAMILIES	JOBS	BUSINESSES
CAMBRIDGE	490	6263	76
SOMERVILLE	166	868	60
TOTAL	656	7131	136

BROOKLINE-ELM

CITY	FAMILIES	JOBS	BUSINESSES
CAMBRIDGE	1235	2366	97
SOMERVILLE	434	349	62
TOTAL	1669	2715	159

EXHIBIT 8 & 9

VII. CONSIDERATION OF MODIFIED PORTLAND-ALBANY ALIGNMENT

As discussed and noted in Section III of this Report, there are many deficiencies in the Cambridge Committee Plan resulting from the Committee's goal of minimizing the displacement of families in Cambridge. To accomplish this goal significant restrictions have been imposed on design development in the Portland-Albany Corridor and has resulted in the serious violation of basic design standards.

Further, the Committee's plan proposes alignment changes in communities adjacent to Cambridge, which are in conflict with prior understandings with these communities. Specifically, the Committee's alignment in Somerville, while grossly substandard, has not been approved by officials of the City of Somerville. Similarly, in Boston the Massachusetts Turnpike Connector has been moved from the Cambridge side of the Charles River to the Boston side without consultation with officials of the City of Boston or the Metropolitan District Commission.

If a highway were to be built in the Portland-Albany Corridor, several modifications have to be made to the Committee's Alignment to: a) upgrade the design to the minimum design standards, b) recognize to

some degree the Department's commitments to the adjoining communities and c) attempt to minimize the complex construction problems by making moderate alignment changes.

In consideration of the above conditions, the major modifications occur at three general locations:

A. The connection to the Massachusetts Turnpike Extension.

B. The area around the Massachusetts Institute of Technology facilities near Massachusetts Avenue (including NECCO) and the Technology Square area.

C. The Interchange with Route 2 in Somerville.

In producing these modifications, the alignment has been kept as close to the Committee's original location as the application of proper design standards will permit.

A. Connection to the Massachusetts Turnpike Extension

The Committee's proposed plan for the Turnpike Connector is discussed in Section III. As noted in the discussion, this plan utilizes a very indirect connection to the Turnpike, especially for the traffic

some degree the Department's commitments to the adjoining communities and c) attempt to minimize the complex construction problems by making moderate alignment changes.

In consideration of the above conditions, the major modifications occur at three general locations:

A. The connection to the Massachusetts Turnpike Extension.

B. The area around the Massachusetts Institute of Technology facilities near Massachusetts Avenue (including NECCO) and the Technology Square area.

C. The Interchange with Route 2 in Somerville.

In producing these modifications, the alignment has been kept as close to the Committee's original location as the application of proper design standards will permit.

A. Connection to the Massachusetts Turnpike Extension

The Committee's proposed plan for the Turnpike Connector is discussed in Section III. As noted in the discussion, this plan utilizes a very indirect connection to the Turnpike, especially for the traffic

originating south of the Charles River and desiring to enter the Turnpike. The same is also true of the return movement. Further, this plan requires elaborate construction staging and expensive detour facilities to maintain railroad and automobile traffic presently crossing the Charles River on the railroad bridge and the Boston University Bridge. It also imposes expressway truck and car traffic on an already overcongested Metropolitan District Commission Parkway, Soldiers Field Road, and encroaches into the Charles River Basin. Both of the last two conditions are unacceptable to the Metropolitan District Commission.

Accordingly, to alleviate the above conditions, the Massachusetts Turnpike Connection has been placed in the Memorial Drive Corridor in Cambridge, tying into the Committee's proposed interchange north of Memorial Drive. To minimize land damages the Turnpike Connector is placed on an elevated structure over Memorial Drive. This modification is shown in Exhibit 2.

B. <u>The Area Around the Massachusetts Institute of Technology and Technology Square</u>

In an attempt to miss the M.I.T. facilities, the New England Confectionery Company and Technology

Square, the Committee has severely constricted the Inner Belt corridor width through this area. The geometric and operational problems resulting from this alignment constriction are discussed in Section III. However, possibly of greater importance, are the additional construction problems imposed in an area where the construction situation is already extremely difficult. The Committee's restrictive corridor will require extraordinary measures for the control of ground water and the underpinning of existing structures in the M.I.T. and Technology Square complexes to maintain the structural integrity of these facilities. Also, construction of a highway so close to buildings devoted to extremely sensitive and important research and development activities could cause complications in the operation of these facilities. The potential liability of the Department could conceivably be very extensive should any damage result.

Accordingly, the alignment has been shifted slightly away from the M.I.T. facilities and the Tech Square complex into the NECCO property and several other adjacent properties. This line shift, while causing an increase in the right-of-way statistics, will help to minimize construction problems somewhat (reduce underpinning requirements and provide a larger construction work area) and possibly minimize potential liabilities to the

Department.

C. <u>The Interchange with Route 2 in Somerville</u>

The geometric and operational aspects of the Committee's Route 2 Interchange are discussed in Section III. As noted in that section, the design deficiencies are numerous. Once again, in their effort to minimize displacements, the Committee has ignored the basic design criteria in the development of the interchange. In addition, several of the interchange roadways have been located in such a manner that a complete relocation and reconstruction of several existing roadways is required to accommodate the Committee's design. The Interchange, for these reasons and for those discussed in Section III, is totally unacceptable.

Accordingly, the upgrading of this interchange to minimum design standards has resulted in a significant modification of the Committee's Plan. The modifications are shown on Exhibit 2. In developing the revisions, the Somerville Industrial Park, located immediately east of the interchange, was used as a major control point since active development of the facility is now underway. However, this interchange plan has not been reviewed by the City of Somerville and, presumably, its

acceptance by the Department would be contingent on Somerville approving this layout.

The alignments of the various interchange elements were positioned to permit reasonable construction coordination with existing structural facilities on present roads. This plan also permits the saving of the Somerville Incinerator.

It should be noted that even though this modified plan is significantly more liberal in design applications, it is still a minimum design and has several undesirable features requiring further study. These include: a) the undesirable viaduct construction over Memorial Drive for the Turnpike Connector, b) the extremely high profiles in the Route 2 Interchange area, etc. Should an alignment in this corridor be chosen for final construction, further studies should be made to eliminate these undesirable design features.

INTERSTATE ROUTE 695
CAMBRIDGE – SOMERVILLE
MODIFIED CAMBRIDGE COMMITTEE ALIGNMENT
1990 DESIGN HOUR VOLUMES
SHEET 1 of 3

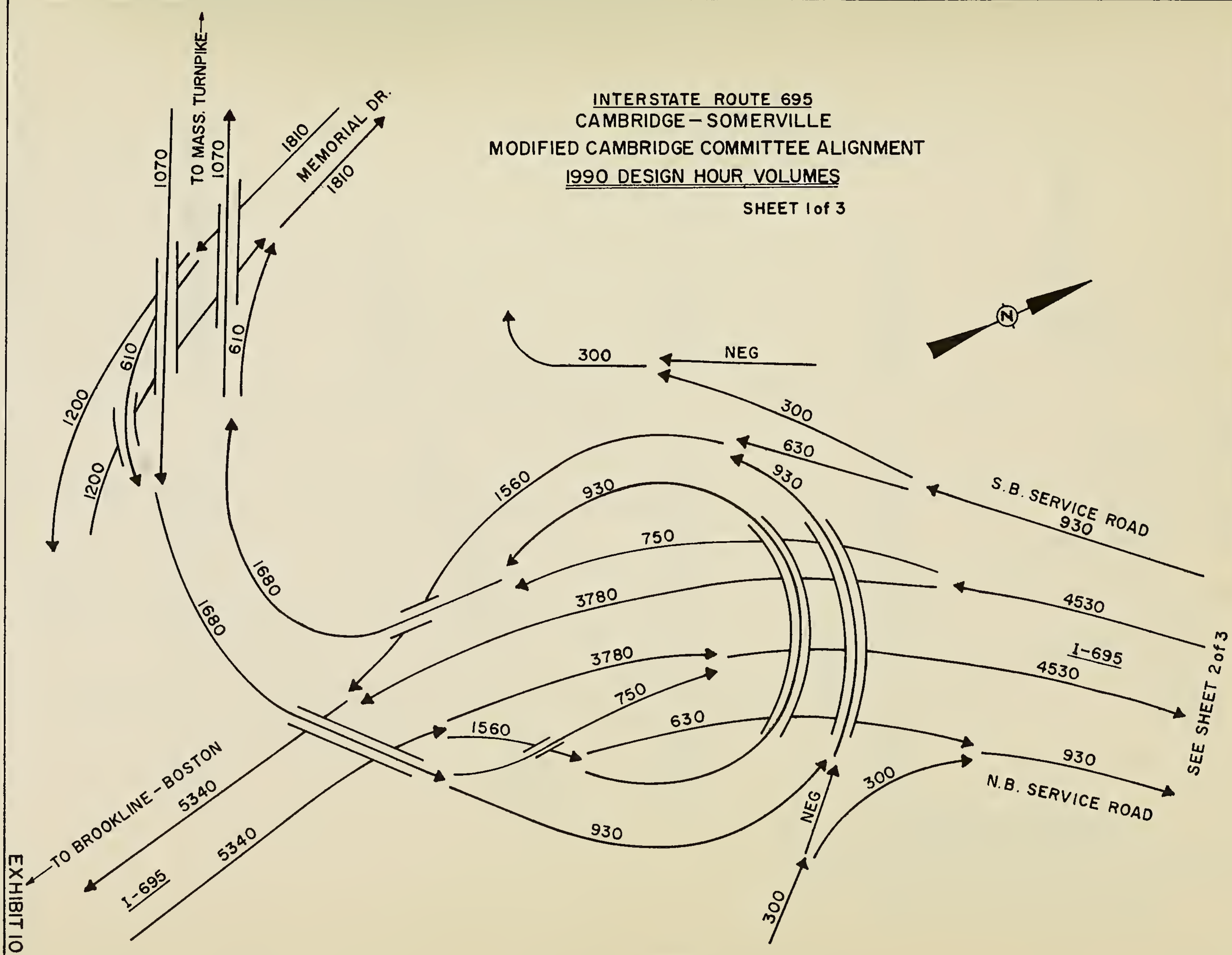
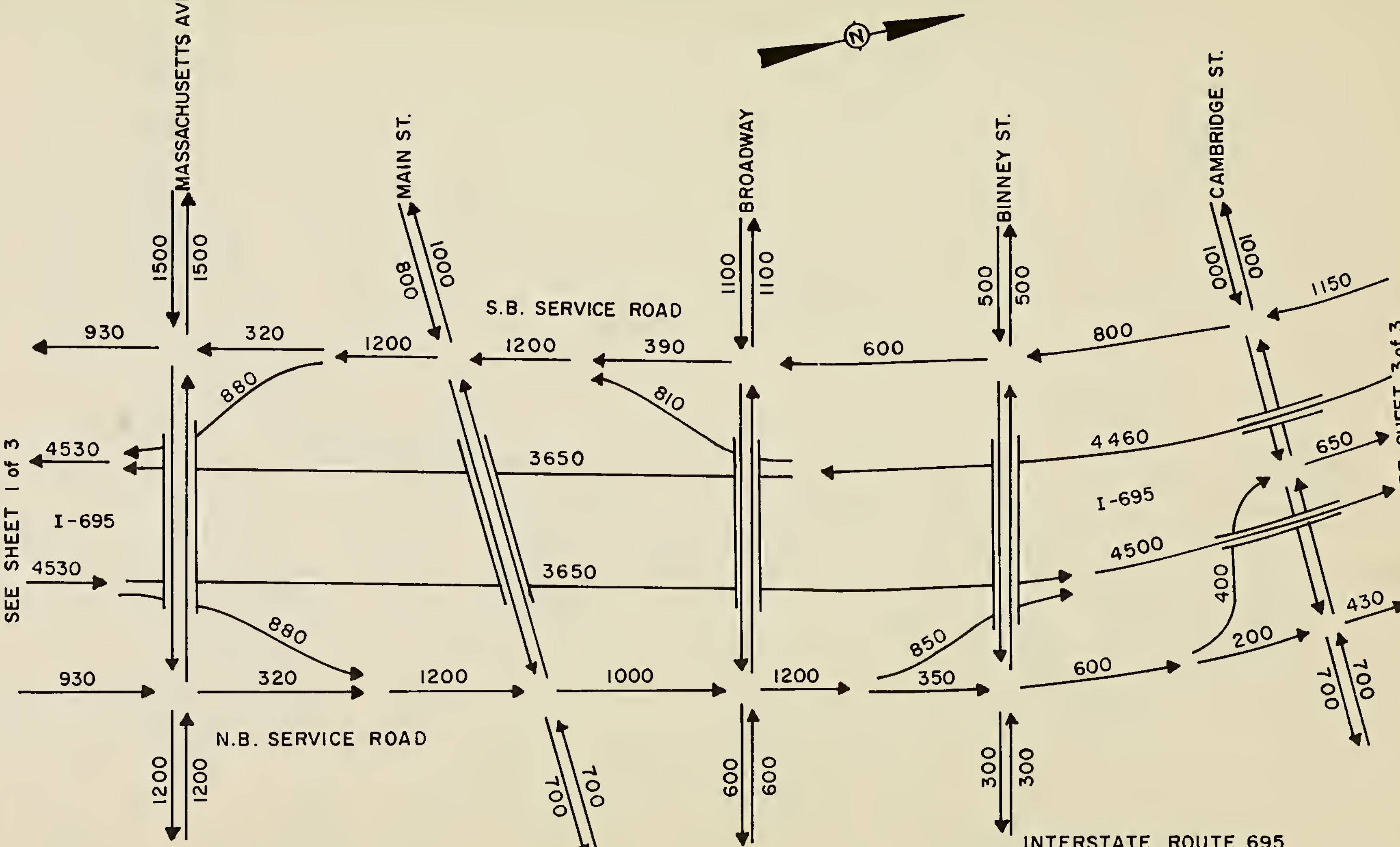
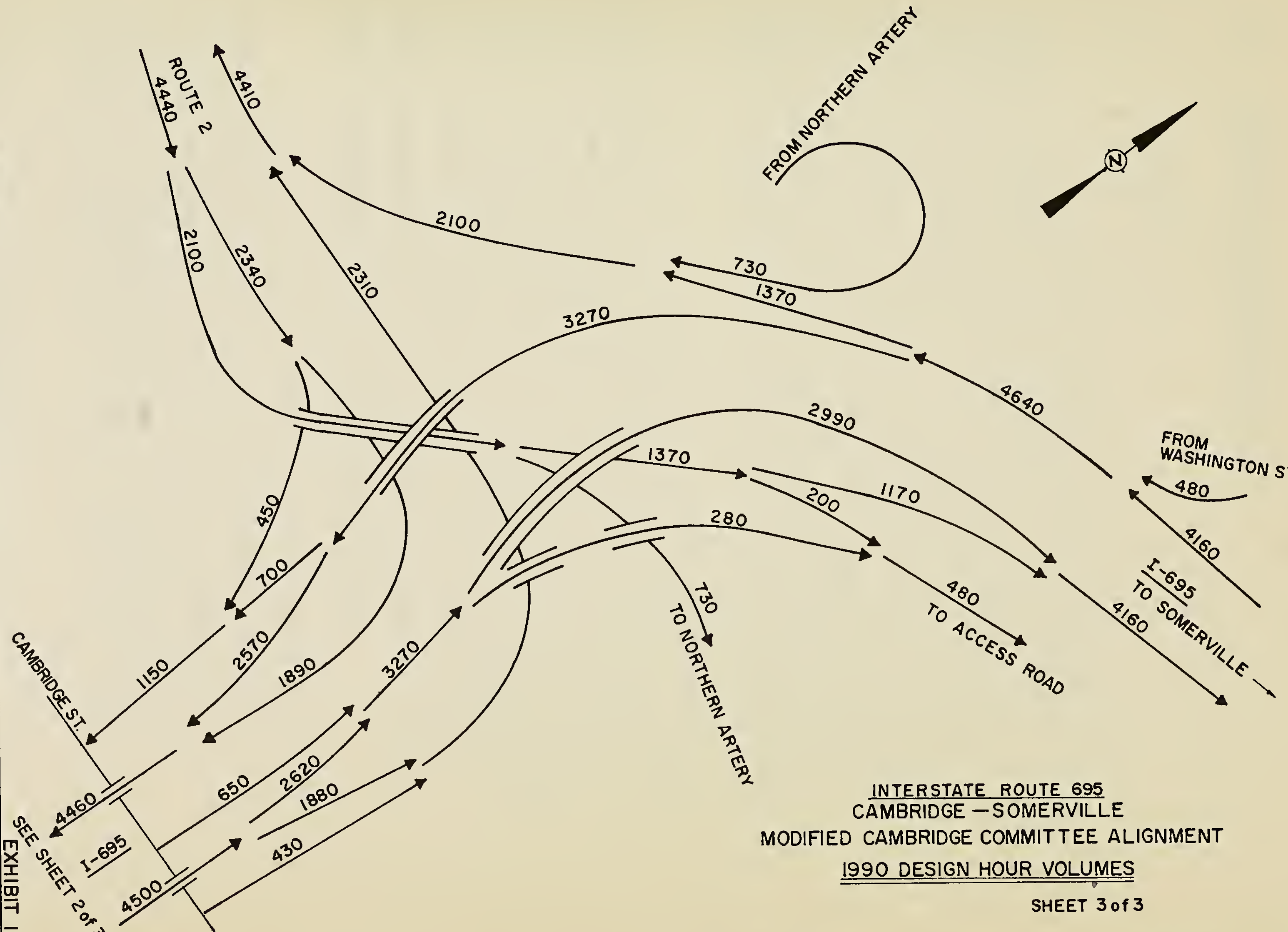


EXHIBIT 10



INTERSTATE ROUTE 695
CAMBRIDGE – SOMERVILLE
MODIFIED CAMBRIDGE COMMITTEE ALIGNMENT
1990 DESIGN HOUR VOLUMES
SHEET 2 of 3

EXHIBIT 11



INTERSTATE ROUTE 695
CAMBRIDGE — SOMERVILLE
MODIFIED CAMBRIDGE COMMITTEE ALIGNMENT
1990 DESIGN HOUR VOLUMES

SHEET 3 of 3

EXHIBIT 12

VIII. SUMMARY AND RECOMMENDATIONS

Summary

In the analysis of the Cambridge Committee's Alignment, it was determined that the line, as presented, did not meet minimum design standards and it would not be acceptable to the Department or the Bureau of Public Roads. It was also determined that the adjoining communities and the Metropolitan District Commission had not given their concurrence to the proposed modifications to the facilities falling within their jurisdiction.

As a result of these findings the alignment proposed by the Committee could have been dropped from further consideration. However, since it had been previously demonstrated that a line in the Portland-Albany corridor was possible, at the request of the Department, the Committee's alignment was upgraded to meet minimum design standards and to have a workable alignment for a direct comparison to the Brookline-Elm Route.

At the direction of the Department, the modifications were kept to an absolute minimum in an attempt to retain the design concepts fostered by the Committee. Through Cambridge, the required geometric changes were very slight, however, they still caused a

substantial increase in the right-of-way requirements and displacement statistics. Route 2 interchange was unacceptable in its entirety and it was completely redesigned. The connection to the Massachusetts Turnpike was returned to the Memorial Drive corridor, because the Metropolitan District Commission indicated that a connector in the Soldiers Field Road location would be totally unacceptable to that agency. As a result of all of these changes, the Modified Cambridge Committee Alignment, shown in Exhibit 2, was evolved, and it is used as the basis for the comparison with the Brookline B Route shown in the Basic Design Report, 1965 by Goodkind & O'Dea, Inc. and previously selected by the Department as the Inner Belt Route through Cambridge. It should be pointed out, however, that while this modified alignment does meet the minimum design requirement, it has not been presented to officials of the adjoining communities and it is subject to their approval.

Comparison of Alternate Alignments

A. Modified Cambridge Committee Alignment

Advantages

1. Limited residential taking.

2. Activity of expressway more in line with

existing industrial area.

3. Located nearer to the source of industrial trucking activity.

4. Alignment cuts through an area which most residents are not directly exposed to.

5. Subway relocation not as difficult.

Disadvantages

1. Extensive industrial taking with serious reduction in the City's tax base and a loss of over 7,000 jobs.

2. Cost $37 million more than the Brookline-Elm Route.

3. Alignment designed at absolute minimum standards.

4. Costly construction methods are required to protect adjoining large buildings during the construction stage.

5. Alignment is not suitable for public housing air-rights development.

6. Roadway is elevated between Binney and Cambridge Streets disrupting the continuity of a depressed highway through the entire City of Cambridge.

7. Frontage roads have at-grade railroad crossings in the vicinity of ramp terminals.

8. Location limits the expansion of industrial and institutional development.
9. Alignment seriously infringes on the Technology Square area.
10. Route does not directly serve bulk of Cambridge's residential population.
11. Requires construction of elevated viaduct over Memorial Drive for the Massachusetts Turnpike Connector.
12. Profiles in the Route 2 interchanges are higher by as much as 15' compared to the Brookline-Elm Route.
13. Access to the Inner Belt from the Somerville Industrial Park is more difficult.

B. Brookline-Elm Alignment

Advantages

1. Cost $37 million less than modified Committee's alignment.
2. Geometric design consistent with the other sections of the Inner Belt.
3. Expressway is depressed through all of Cambridge opening possibilities for development of public air-rights housing.

4. Location reinforces the geometry of existing street pattern.
5. Gives a more balanced over-all traffic service.
6. Permits the orderly development of the industrial - institutional area.

Disadvantages

1. Heavy residential takings.
2. Introduces a temporary divider between residential neighborhoods.
3. Subway reconstruction more difficult.

Recommendations

The only distinct advantage that the Modified Cambridge Committee Alignment has over the Brookline-Elm Route is the small number of residential displacements. In all other respects the Brookline-Elm Route is by far the superior of the two.

The Department of Transportation is vigorously promoting the joint freeway and urban development concept. Federal-aid money is available for the development of public air-rights housing. The Brookline-Elm Route is depressed through all of Cambridge and it is ideally suited for model air-rights developments. Consequently, it can be stated with confidence that the

residential displacement caused by the construction of the Brookline-Elm line should only be of temporary duration and, whenever the need should arise, housing over the expressway could be constructed at a very low cost to the community and the residential units taken for the expressway could be easily replaced.

Therefore, upon consideration of highway construction costs, difficulty of construction in the Portland-Albany Corridor, and the long-term effects on the City of Cambridge, it can only be concluded that the Brookline-Elm Route would result in a far better total highway for the City of Cambridge, Commonwealth of Massachusetts and the motoring public and we strongly recommend the selection of this route.

APPENDIX

SOILS CONDITIONS ALONG THE CAMBRIDGE COMMITTEE ALIGNMENT INTERSTATE ROUTE 695 CAMBRIDGE, MASSACHUSETTS

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JAMES P. COLLINS & ASSOCIATES INC.

SOILS CONDITIONS ALONG
THE CAMBRIDGE COMMITTEE ALIGNMENT
INTERSTATE ROUTE 695
CAMBRIDGE, MASSACHUSETTS

By:

JAMES P. COLLINS & ASSOCIATES, INC.

Consulting Soils and Foundation Engineers

APRIL 1967

I. INTRODUCTION

The Cambridge Committee has proposed a route for the "Inner Belt" (Interstate Route I-695) which crosses the Charles River just downstream of the Boston University Bridge, and then follows generally Albany Street in Cambridge. This report summarizes the findings of a study made by James P. Collins & Associates, Inc., Consulting Soils and Foundation Engineers, of the soil conditions likely to be encountered along this route.

The proposed alignment differs somewhat from another route in the vicinity of Albany Street which was studied in detail by Goodkind & O'Dea, Inc. in their 1965 Basic Design Report. This report follows the Goodkind & O'Dea nomenclature by referring to their alignment as "Albany D"; the Cambridge Committee route is referred to simply as the Albany Street Alignment. For ease of reference in the following discussion, Albany Street is assumed to run north and south (northerly toward Somerville) while Massachusetts Avenue and Main Street run westerly from the River toward Central Square.

The information on which this report is based was obtained from a number of sources, including M.I.T. publications, the Polaroid Corporation, the Cabot, Cabot and Forbes Company, New England Confectionery Company, other consultants, and the author's personal experience in the area. No new borings or other explorations were made.

The investigation has been limited to that portion of the proposed alignment between the Charles River and Cambridge Street. North of Cambridge Street no major buildings are

encountered and soil conditions are essentially the same for any of the routes being seriously considered.

For the greatest part of its length the alignment proposed by the Cambridge Committee is a depressed section between retaining walls. The surface of the proposed roadway is approximately 23 feet below existing grade over most of its length. Some additional excavation will be required below finish grade; about 12 feet is necessary if a conventional concrete mat is used to resist hydrostatic uplift pressures. Thus as much as 35 to 40 feet of total depth of excavation may be required for most of the main line. Even deeper excavations are required for the approach to the proposed Charles River Tunnel and the relocated M.B.T.A. tunnel which must pass under the highway.

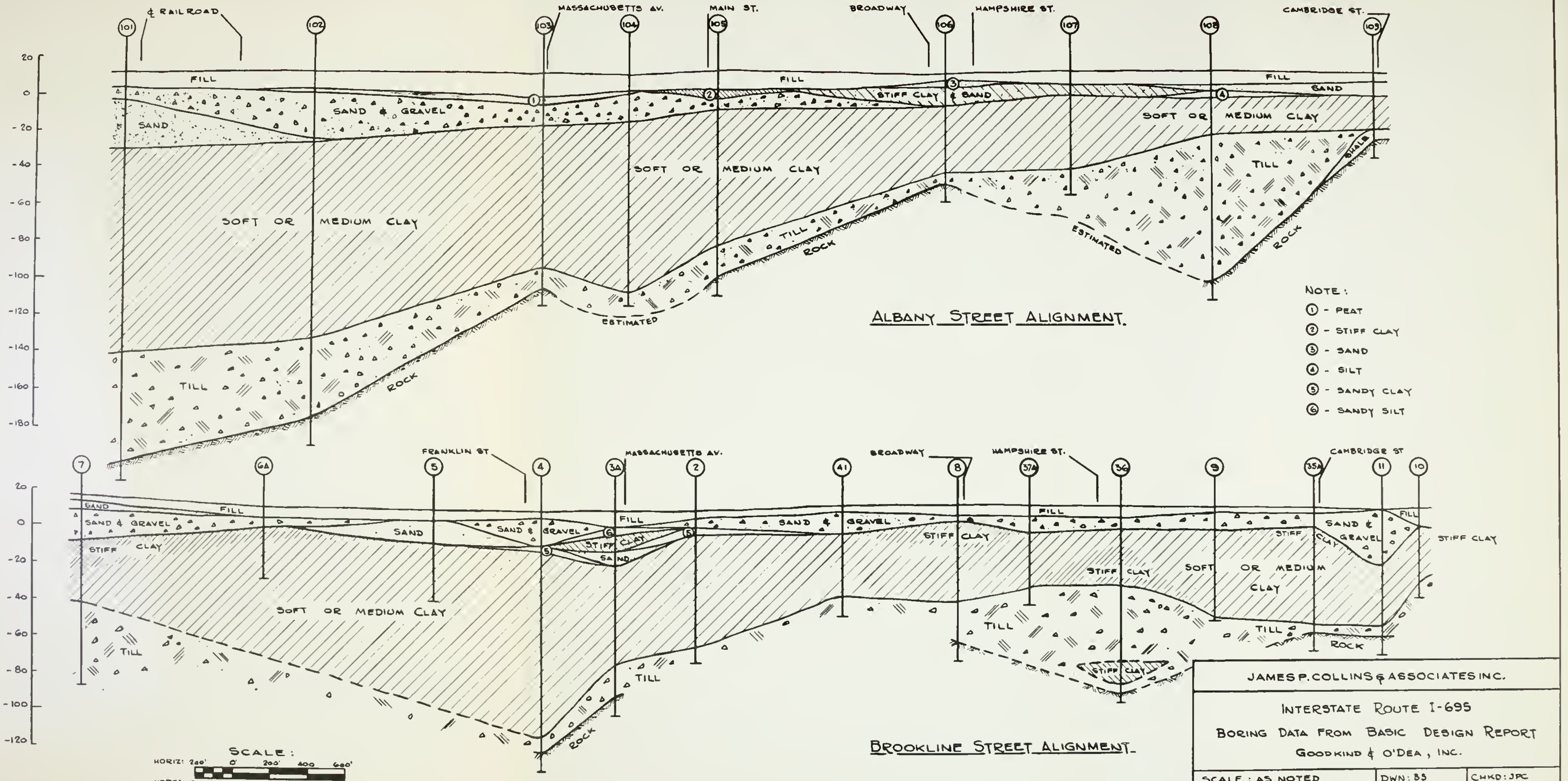
II. SOILS ENCOUNTERED

The soil profile encountered in this area of Cambridge is representative of large parts of the Boston Basin. A large body of experience has been accumulated in the design of heavy construction for these subsoils. As a result, their presence and properties can be predicted with considerable confidence. Soil profiles along the Albany Street and Brookline Street alignments have been prepared from the Goodkind & O'Dea borings and are shown in fig. 1.

In order downwards, five general layers of soil can be anticipated. The greatest part of the route lies within what was once the Charles River estuary and consists of filled marsh land. The upper surface materials are therefore invariably artificial fills of considerable age and mixed quality. Because large quantities of cinders were dumped in this area during the coal burning era of the railroads,the fills are both permeable to groundwater and corrosive to buried structures.

Beneath the fills are the peats and organic silts which were the surface deposits in the old marsh. These vary from highly fibrous peats to slightly organic silts. There is a general tendency for the deposit to be thickest (12-15 feet) at the Charles River and to decrease in thickness toward the west.

The undrained (short term) shear strength is low, typically 200-600 psf. Drained (long term) strength is higher, friction angles up to 45^{o} having been measured. Usual values appear to be 30 to 35^{o}. The organics are only slightly overconsolidated and are very compressible. Typical



JAMES P. COLLINS & ASSOCIATES INC.

INTERSTATE ROUTE I-695
BORING DATA FROM BASIC DESIGN REPORT
GOODKIND & O'DEA, INC.

SCALE: AS NOTED	DWN: BS	CHKD: JPC
APRIL 1967	FIGURE 1	

compressibility indices are 0.3 to 0.5 for the silts and 1 to 2 for peat.

Below the peats is a layer of sand and gravel. Except for a few small areas where it pinches out, the stratum is continuous over the entire vicinity of the proposed Albany Street Alignment. Where its vertical section has been exposed in building excavations, it appears to be lenticular rather than stratified in structure, particularly in the southern parts of the M.I.T. campus. Some of these lenses consist entirely of fine to medium gravel. Because of the erratic structure, groundwater patterns are difficult to predict quantitatively, but in general the deposit is extremely permeable. The nearby Charles River appears to have little short-term effect on the water levels in this stratum, probably because the fine river silts have been laid over the exposed edge of the sand deposit.

Below the sand is a deep deposit of the well known Boston blue clay. The upper portion of the clay has been dried sometime in the geologic past and is heavily overconsolidated at its upper surface. The overconsolidation becomes progressively less with increasing depth until at about elevation -60 to -70 the clay is normally consolidated for the remainder of its depth. In the normally consolidated domain, the compressibility index is of the order of 0.25 to 0.50. The recompression index in the overconsolidated regime is of the order of 0.04 to 0.06 from laboratory tests and about 0.025 to 0.03 from field measurements.

Perhaps the single most important soil property for this study is the shear strength characteristics of the clays. The strength parameters define the factor of safety against

deep shear failure of these major excavations. This problem is one of the major subjects of Section V; it will be shown there that the values assumed have a central bearing on the technical feasibility of the proposed alignment. The shear strengths shown on fig. 2-1 on p.23 have been taken from fig. 4.9 of an M.I.T. publication.[1] These values are about 50% greater than those determined by conventional testing procedures, and are believed to be the best available estimates of the true strength of the clay. However, these strength values are unlikely to be confirmed by laboratory testing, and some reservations remain about their use in final design. On the other hand, conventional testing procedures often seriously underestimate shear strength. In summary, the shear strengths of the clays are significantly uncertain; the Ladd-Luscher values have been used here as the highest supportable estimate available.

The upper surface of the clay is approximately horizontal, while the lower surface slopes upward to the west and north. The clay disappears completely in the Central Square area. In the vicinity of the Brookline Street alignments the clay deposit is less deep than along the Albany Street alignment, particularly in the southerly portions of the Section. With the exceptions of borings 3A and 4, none of the borings along the Brookline alignment reveal a depth of clay that extends below elevation -60. Along this route all the clay can be expected to be overconsolidated. The depths of clay are much greater along the Albany Street route and the stiffer, over-consolidated materials are underlain here by softer, normally

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1. Ladd, Charles C., and Luscher, Uhlrich, The Engineering Properties of Soils Underlying the M.I.T. Campus, M.I.T. Soil Mechanics Publication 185, December 1965.

consolidated clay. Fig. 1 shows the difference in the depth of the clay along the two alignments.

Beneath the clay and lying just over the rock is the thin layer of "glacial till", which covers the bedrock over most of New England. This is a very well graded silt, sand, and gravel overridden by the massive glacier that once covered New England. Because of the mechanism of its formation, it is predictably dense, generally unstratified, and almost never overlies any weak or compressible soil.

The bedrock in the area consists predominately of two general rock types. The first is altered Cambridge Shale, a dense, dark blue-gray slate that is generally hard and sound. The other rock, which should be anticipated in the northern reaches of the proposed alignment, is an anomolous material variously called siltstone, shale, or argillite. It is an extremely soft, almost chalky, very light colored, grey-green sedimentary rock. The unconfined compressive strength of intact samples is in the range of 12 to 16 tons per square foot.[2] However the few times it has been uncovered it has been seen to be extensively fractured and jointed, and its engineering properties on a large scale are uncertain.

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2. Ladd and Luscher, op. cit.

III. GROUNDWATER

The groundwater table is relatively constant throughout the area at about elevation 0, 20 to 25 feet above the bottom of the proposed excavation. The large excavations necessary for the Albany Street alignment will require a major dewatering effort. For reasons discussed in Section V, the water table outside the excavations cannot be lowered for more than a few months by more than 1 or 2 feet.

Because of the pervious sand and gravel stratum, it is impractical to attempt to dewater this excavation by open pumping or wellpoints. The quantities of water pumped would be enormous, perhaps as high as 20 gallons per minute per foot of highway. Within a few days or weeks, the water table outside the excavation would be drawn down nearly to the bottom of the excavation for as much as a thousand feet on both sides of the construction. Some drawdown of the water table would occur at even greater distances.

The difficulties of dewatering an open excavation in this area can be illustrated by a single example. The basement excavation for the Married Students Housing at the south end of the M.I.T. campus was made in 1962. The excavation was 36 feet deep, just below the bottom of the sand stratum. The excavation was small by highway standards, only 80 feet square at the bottom. The sides of the excavation were sloped back to avoid the use of sheet piling, and a two-stage wellpoint system was used to dewater. The water table was monitored continuously with observation wells during the ten months required to complete the building structure.

To dewater this small excavation, 800 gallons per minute were pumped from the lower stage wellpoints. Less than eight hours after these second stage wellpoints were put in operation, the first stage wellpoints went dry because the water table had dropped below their points. Within three days, the water level in all the observation wells, the farthest of which was 400 feet from the crest of the excavation, had been depressed 25 feet. Piezometers at the Materials Science Center, more than a half mile away, showed a drop of four feet within a few days. The Earth Sciences Building, three-quarters of a mile away, was under construction at the same time. The Superintendent reported that when the second stage pumping was started at the Married Students Housing, a water bearing sand stratum that had been a problem to him for weeks had suddenly gone dry.

An attempt was made to recharge the groundwater to prevent damage to property on the opposite side of Vassar Street. Recharge rates as high as 1500 gallons per minute were tried without the water table being raised significantly. No improvement was recorded in an observation well that was only 10 feet from the nearest recharge well. After the structures had been completed to a weight sufficient to balance the water pressure, the wellpoints were removed. The water table returned to its original level in 4 days. Similar experiences on a smaller scale had been reported during a much shallower excavation for McCormick Hall on Memorial Drive.

These experiences indicate that groundwater control by pumping will cause a major drawdown of the water table over a wide area. Moreover, it must not be assumed that a single row of sheet piles, or any other conventional technique,

will confine the drawdown within the excavation. Both theory and experience have shown that a bulkhead must be nearly perfectly watertight if the water table outside the excavation is to be maintained at its initial level. Because of their loose tolerances, and accidental misalignment, sheet piles are almost useless for this purpose. Many examples on similar sites, both in southeastern Cambridge and elsewhere in Greater Boston, support this conclusion.

In summary, experience shows that maintenance of groundwater elevations during excavation for the Albany Street alignment will be impossible in conventional construction. The serious implications of an extensive drawdown, together with some unusual construction procedures to prevent it, are discussed in Section V.

IV. EXISTING CONSTRUCTION

The Albany Street alignment passes through a narrow corridor within a heavily built up area of Cambridge. Some M.I.T. buildings, as well as several major office buildings and a number of two to four story industrial buildings, are immediately adjacent to the proposed highway. An important object of this study was a preliminary estimate of the cost of underpinning or other special measures required to protect these buildings.

No new subsurface investigations were made. However, most owners were cooperative in making building plans and soil information available. Information on the M.I.T. buildings has been published in the reports of a program called Foundation Evaluation and Research, M.I.T., or FERMIT. Other sources, such as the office of the Cambridge Building Commissioner and the reports of design consultants, were also investigated. In addition, each building along the route was examined visually for preliminary information on size, height, structural characteristics, etc. The data assembled in this investigation are summarized in Table I and the discussion which follows. The conclusions from the study are presented in Section V.

Table I shows the foundation data for the principal buildings which lie close to the highway or the deep excavation necessary to relocate the M.B.T.A. tunnel. Some of these buildings warrant further discussion.

The building occupied by the Polaroid Corporation at the corner of Brookline Avenue and Memorial Drive was originally built as a Ford assembly plant in 1913. Two

TABLE I

SUMMARY OF FOUNDATION DATA FOR MAJOR BUILDINGS ADJACENT TO HIGHWAY AND RELOCATED TUNNEL EXCAVATIONS

Asterisk denotes further discussion in text. n.a. denotes not available

Building	Principal Use	No. of Stories	No. of Basements	Foundation Type	Bearing Elevation (approx.)	Bearing Stratum	Basement or First Floor Slab
M.I.T. Buildings:							
National Magnet Laboratory Complex							
Building NW13	laboratory	2	0	n.a.	n.a.	n.a.	slab on grade
Building NW14	laboratory	3	1	n.a.	n.a.	n.a.	structural
*Building NW15	laboratory	5-3	1	concrete piles*	-3	sand	structural
				steel H-piles*	n.a.	n.a.	
Nuclear Engineering Center							
Building NW12	laboratory	3-2	0	footings	0	sand	slab on grade
*Nuclear Reactor	reactor	3	1	mat	0	sand	mat
Instrumentation Laboratories							
Buildings N11, N12, N13, and N14	laboratory	5	1	footings	0	sand	slab on grade
Building NW30	laboratory	3	1	n.a.	n.a.	n.a.	n.a.
High Voltage Laboratory							
Building N10	laboratory	3	1	caissons	0	sand	structural
Technology Square Buildings:							
Building Alpha	office	9	1	mat	-2	sand	mat
565 Technology Square	office	9	1	mat	-1	sand	mat
Two Story Building	office	2	1	mat	-1	sand	mat
Polaroid Corporation Buildings:							
600 Main Street	office	1	n.a.	n.a.	n.a.	n.a.	n.a.
730 Main Street	office	5	1	n.a.	n.a.	n.a.	n.a.
748 Main Street	office	5	1	n.a.	n.a.	n.a.	n.a.
758 Main Street	office	5	1	n.a.	n.a.	n.a.	n.a.
764 Main Street	office	5	1	n.a.	n.a.	n.a.	n.a.
*Brookline Avenue and Memorial Drive	office and light mfr.	5	1	footings or timber piles*	n.a.	n.a.	slab on grade
New England Confectionery:							
Company Building	office and light mfr.	4	1	footings	0	sand	structural

foundation plans exist, one showing footings and the other timber piles. There is no way of knowing which was used. The basement floor is a slab on grade placed on a pad of compacted gravel over the peat.

This slab has settled badly over the years and has caused extensive damage in the basement. This is unquestionably due to compression of the peat; the main structure is not affected. The slab itself is broken and uneven, and cracks 2 to 3 inches wide are found in relatively recent concrete block partitions. It has been necessary to suspend four boilers from the ceiling to prevent further settlement; their associated well water pumps have been fitted with screw jacks and are re-aligned weekly.

The settlement was noticeably accelerated in 1966 during construction of a nearby M.D.C. sewer. One crack opened 3/8 inch between June and October. The basic fill was found to have settled away from the slab by as much as six to eight inches, although it is not known how much of this is attributable to the M.D.C. construction. This building is an unmistakable example of the compression of the peat stratum which follows immediately on a drawdown of the water table. Reference is again made to Section V where the effects of drawdown are discussed in greater detail.

Probably the single most critical building for this study is the Alpha Building in Technology Square. A modern reinforced concrete office building with the large bays (27 feet x 27 feet) typical of recent designs, it is founded on a concrete mat which is continuous across the entire structure except for two construction joints. The mat is

4 feet thick under columns and walls and 3 feet thick elsewhere. Extensive settlement data, boring information, soil test data, and complete structural plans are available for this building. The settlement data and a typical boring log are shown in fig. 2-1. The gross area load (i.e., total weight of building divided by total area of mat) of this building is about 2700 pounds per square foot. The net area load (weight of building less the weight of soil excavated for the basement) is 1300 psf. Individual column loads range from 310 tons at the corners to about 1000 tons at the interior columns.

Building Alpha is not only one of the heaviest encountered along the proposed alignment; it is also in the most critical location. The highway excavation, approximately 40 feet deep, passes about 20 feet from the northwest corner of the building. The relocated M.B.T.A. tunnel, perhaps as much as 60 feet deep, runs parallel to the south end of the building about 50 feet from the mat. The exact geometry is difficult to establish because precise surveys are not available, and both the width and depth of the excavation will depend on the construction methods adopted. This building has been examined for a detailed underpinning study presented in Section V.

It is apparent from Table I that buildings of moderate size in this area are consistently founded on the sand stratum. The actual foundation members used to accomplish this have varied widely, but this will not seriously affect the need or cost of underpinning. It will also be noted that the lowest floor is frequently a slab on grade; the slab and anything it supports are therefore liable to damage if the underlying organics are compressed for any reason.

In addition to the buildings described above, there are a number of one and two story light industrial buildings which are close to the proposed alignment. With the exception of the Nabisco building, there are no plans or subsurface data for any of them. However, it is reasonable to suppose that they, too, are founded on the sand stratum. It is also probable that some are founded on short timber piles; their use was widespread in the period between the wars when many of these buildings were built, and they were then (as now) an economical choice for light loads.

A broader survey was also undertaken of important foundations not immediately adjacent to the excavation but still within the range of an inadvertent drawdown of the water table. A wide variety of foundation designs has been encountered, but they appear to fall into three general classes.

Light buildings up to about five stories follow the practice described above of bearing on or in the sand and gravel stratum. Belled caissons and (probably) timber piles are common with older buildings; many of the newer structures use Franki or cast-in-place concrete piles. Many industrial buildings use slabs on grade, while more substantial structures (such as most of the recent M.I.T. additions) use a structural basement slab.

There are a number of heavier buildings up to about sixteen stories which use floating or semi-floating foundations. Examples are the M.I.T. Married Students Housing on the south end of the campus and the buildings at Technology Square. These designs use deep basements so that the weight of the soil excavated is as great (or nearly so) as the weight of

the building. The soft clays at depth feel a much reduced new load and hence compress very little. This is a very successful device for economical control of settlements, but leaves the building vulnerable if the clay should later compress for other reasons.

The very large buildings, such as the Earth Sciences Building and the new Married Students Housing near Kendall Square are founded on deep piles which penetrate the clay and carry the loads to the till or rock beneath. The most common type is a concrete filled pipe pile. These structures are the least susceptible of all to damage from the construction operations for the Inner Belt.

V. DISCUSSION AND EVALUATION

An appraisal of the feasibility of the Albany Street alignment must take account of three major soils and subsurface problems: maintenance of the water table, stability of the deep excavations, and protection of adjacent buildings. The previous sections of this report have presented the basic information necessary to define those problems; this section discusses them and presents some possible solutions.

A. Maintenance of Groundwater Levels

The difficulties in maintaining and controlling the groundwater levels while opening deep excavations have been discussed in Section III. Yet it is imperative that the water table be maintained, both during and after construction. Depression of the water levels for more than brief periods will cause an increase in load on the underlying soil. As the soil compresses under the new load, the buildings above will settle a corresponding amount. Since settlement is always erratic, there is an attendant risk of widespread damage and, in the extreme, dangerous structural distress.

When the load on a fine grained soil is increased by lowering the water table, the accompanying compression strains take place slowly over long periods. The process is identical to the familiar consolidation which causes long term settlement of embankments, structures, and other heavy construction. Pore water must be extruded from between the grains to allow the soil skeleton to compress. Because of the hydraulic resistance in the microscopically fine pores, this process may take months or even years to be complete. The time required is greater for finer grained soils. It also increases approximately as the

square of the thickness of the deposit.

This conclusion - that lowering the water table will effect an increase in load on, and accompanying compression of, the underlying soil - is easily predictable from elementary theories of soil mechanics and has been amply verified by costly experience. Quantitatively, the increase in vertical pressure is equal to the unit weight of water (62.4 pounds per cubic foot) times the vertical distance of drawdown. For example, if the water table is lowered 20 feet, the soil reacts as if a uniform load of 20 x 62.4 = 1248 pounds per horizontal square foot were spread across the surface over the entire area of the drawdown. In physical terms, this is equivalent to placing gravel fill to a height of about 10 feet over that area. A drawdown of 20 feet is entirely possible, as the experience of the M.I.T. Married Students Housing confirms.

Both the organic stratum and the soft normally consolidated deep clay deposit would compress substantially under these loads. Compression of the deep clay deposit will cause settlement of all of the nearby buildings whose foundations do not penetrate this layer. This includes all but the very heavy recent additions to the M.I.T. campus. The damage caused by this settlement would depend on the amount of the settlement (hence the extent and duration of the drawdown), the structure and size of the building, and many other factors. From settlement records of large buildings in Boston, it would appear that settlements of the order of 6 to 8 inches are likely if a 20 foot drawdown is sustained for a 3 year construction period; 8 to 12 inches, and locally even more, are probable if the drawdown is permanent. Very few buildings can tolerate that order of settlement without severe distress.

The peat is even more compressible and would respond within a few weeks as evidenced by the damage cited in the Polaroid building. For the most part this damage would be limited to the basement slabs and any equipment and partitions which rest on them. In almost every case, the foundations for the columns and walls penetrate the peat and the main structure is not endangered. There is an important exception to this conclusion which should be recognized, however.

When the peat compresses under the new loads, negative skin friction develops on the foundation elements which penetrate it. Vertical friction along the sides of the piles prevents compression of the soil immediately adjacent to them, so that part of the load applied to the peat is transferred to the pile. For the most part, this is likely to become a serious problem only in the case of timber pile foundations, but here the results can be catastrophic. The overload can develop to magnitudes which cause a sudden failure of the pile. This phenomena was blamed for the collapse of a market in Quincy several years ago.

In summary, a severe water table drawdown in the vicinity of the proposed Albany Street alignment will almost certainly cause widespread and troublesome damage to basement slabs because of compression of the peat stratum. If sufficiently prolonged, that compression is capable of causing catastrophic collapse of timber pile foundations. Prolonged drawdown may also cause compression of the soft blue clays and settlements large enough to endanger almost all the buildings in the area.

Since the water table can be counted on to return to its equilibrium level within a few days after the removal of any

unsettling factors, the duration of the drawdown is of considerable importance. The experience at the Married Students Housing and elsewhere in the area suggests that even a major drawdown can be tolerated for about six months if the decision is made to risk troublesome but not dangerous settlement.

It is apparent that unusual construction and design or both will be required to meet the difficulties of groundwater control. One approach is to take advantage of the time dependency of the soil's response and construct the highway in short segmants, so that no major dewatering lasts for more than a few months.

An annual construction cycle can be envisioned in which excavation and dewatering of a single segment is carried out during the winter months with the structural slab and retaining walls placed as early in the spring as weather permits. The groundwater would then be permitted to return to its natural level during the remainder of the year while all construction was completed on that section of the highway. The cycle might then be repeated for the adjacent segment. This procedure, while highly unusual, would permit construction with a drawdown of the water table for three or four months each year. No effort has been made to examine the impact of this segmental construction on the cost of the highway construction.

Alternately, highway designs may be adopted which can be expected to maintain the water table outside the excavation continuously at its normal elevation. Both the design and construction of such a cross-section are novel, complex, and expensive. Such a cross-section might incorporate a heavy slurry trench wall to extend below the slab into the underlying

clay. The slurry trench technique, to the author's knowledge, has never been used in highway construction, but has been used for a similar problem in constructing a deep building basement in Back Bay, Boston. It has been proposed for a number of subway designs in the United States, and was used with considerable success on the Toronto, Montreal, and Milan subways.

The technique consists in excavating a deep trench, the sides of which are maintained by keeping the trench continuously filled with a carefully controlled drilling mud. Reinforcing steel cages are lowered into the mud, and tremie concrete placed from the bottom, displacing the mud upward. These walls become the side walls of the highway cross-section. After their completion, the excavation is carried out between them for placement of the structural slab.

If the walls are carried 5 to 10 feet into the clay stratum below the bottom of the excavation, water can leak into the excavation only by taking a lengthy route under the toe of the wall through a very impermeable soil. The resulting seepage is very likely to be less than the rate of the evaporation and as a result the hole will be usably dry. The only problems are likely to spring from small occasional leaks and imperfections in the wall.

A slurry trench wall is a novel solution, but it might be an economically viable one. A 24" wall of this construction at 180 Beacon Street in Boston cost about $11 a square foot. A thicker wall will of course be more expensive, but the unit price will be lower because of the larger scale of a highway project. The high unit price is offset in very large measure by the elimination of any sheet piling and, in the ideal,

the nearly complete elimination of pumping costs. Despite its novelty, a slurry wall is worthy of serious evaluation.

The slurry trench technique can be generally regarded as proven in practice, but there are many aspects of detailed design which are still unresolved. Many variations are possible in the way it is incorporated into a highway cross-section. It might, for example, be made thick enough to act as an unbraced bulkhead, so that all interior bracing could be eliminated in the excavation. The panels might also be precast to eliminate the cost of interior finish. These and many other possibilities are conceptually workable, but have never been tried in actual construction. For this reason, it is urgently recommended that a slurry wall not be attempted without a pilot program in the field to test the design criteria.

Probably the most expensive possibility, but also the most conventional, is the use of a cofferdam to contain the water outside the excavation. These might be cellular cofferdams, excavated and backfilled after excavation with impervious material such as the organic silts which will be encountered in the highway excavation. The excavation might be partially completed, leaving a berm along the outside edges, and the organic material being placed in cofferdams under concurrent construction. Alternatively, a double row of heavy sheeting might be used for the same purpose, with the material between the sheets removed and backfilled with the impervious soil.

It has been pointed out in Section III, and must be re-emphasized here, that a single row of sheet piles does not offer any effective hydraulic resistance. The use of sheet

piles for this purpose by contractors is common, but almost universally ineffective. There is ample evidence, both emperical and theoretical, that the pressure drop across a single row of ordinary steel sheets is almost always negligible, and they are nearly useless in maintaining the water table outside the excavation.

The third possibility is to attempt to grout the sand stratum. If this possibility is technically feasible, it is probably the simplest and most direct of all of the available alternatives. The author is skeptical of the possibility of plugging the very open gravel lenses in the troublesome sand deposit with any useable grout. However, there is limited local experience to confirm this judgment, and careful and extensive field tests are necessary before this alternative can be adopted.

B. Stability of the Proposed Excavations

The proposed highway excavation will be about 35 feet deep for a conventional "boat" section, about 30 feet deep for a roadway with the subgrade drained between watertight barriers, and about 25 feet deep for an anchored pavement. The highway cuts will be about 150 feet wide. Since the Albany Street corridor is too narrow for side slopes, the walls will be vertical and braced. The excavation for the M.B.T.A. realignment will be about 55 or 60 feet deep, but only 20 or 25 feet wide. Some form of sheeting and cross-trench bracing will be required. The stability of these cuts must be considered.

It is possible to install sheet piling and bracing that will prevent a shear failure along a plane surface behind

the sheeting and above the toe of a cut. Another failure surface, circular or nearly so, could pass under the toe of a wide excavation and emerge within it, causing a soil mass with sheeting and bracing to rotate as a unit into the excavation. A similar failure could engulf a retaining wall. Any of these possible failure modes can be analyzed as a problem in slope stability using one of the methods of slices. In a narrow trench, such as the M.B.T.A. excavation, the bottom could heave upward if the cut were too deep, even though the sides were rigidly braced. This type of failure can be handled as a negative bearing capacity problem. It should be obvious that either type of failure would be catastrophic, since any building founded in the rotating mass will also fail.

The wide roadway excavations will be examined first, since some of this discussion is also relevant to the deeper, narrower cut for the M.B.T.A. realignment. The object of this analysis is to estimate the factor of safety for the least stable excavation likely to be required, to examine the variables which influence the factor of safety, and finally to evaluate the Albany Street alignment in the light of the safety of the excavations.

The stability of the proposed excavations must be considered for all the following conditions:

1. Immediately after the cut is made. For this condition, the undrained strengths of the clay are the important engineering properties.
2. At some time after the cut has been made, when the clay has swelled and lost some of its strength, but before permanent retaining structures have been built.

3. Long-term, after completion of the construction, when pore pressures have returned to their normal hydrostatic values. For this condition, the stability is governed by the effective stress strength parameters of the clay.

Figure 2.1 shows a vertical cut deep enough to accomodate a boat section with a bottom slab about 12 feet deep. The results shown are for conditions immediately after the excavation is made. The major uncertainty, by far, in this analysis is the values that should be used for the undrained strengths of the clay; particularly, the deep, normally consolidated clay. Figure 2.1 shows results for three different assumptions about the strength of the deep clay. These are identified by (a), (b), and (c) on the figure. The strengths indicated by (a) were taken from an M.I.T. publication[1] and are believed to be the best estimates available of the true strengths of the clays that will be encountered in that part of the Boston basin. This strength distribution[2] through the soil profile shows the strength decreasing from about 2500 psf to 1200 psf in the overlying overconsolidated clay and increasing at about 15 psf per foot in the deeper, normally consolidated clay. The critical trial failure surface is shown on figure 2.1 and has a factor of safety of about 1.5.

The interpretation of this value deserves discussion. For the problem illustrated in figure 2.1, the value of

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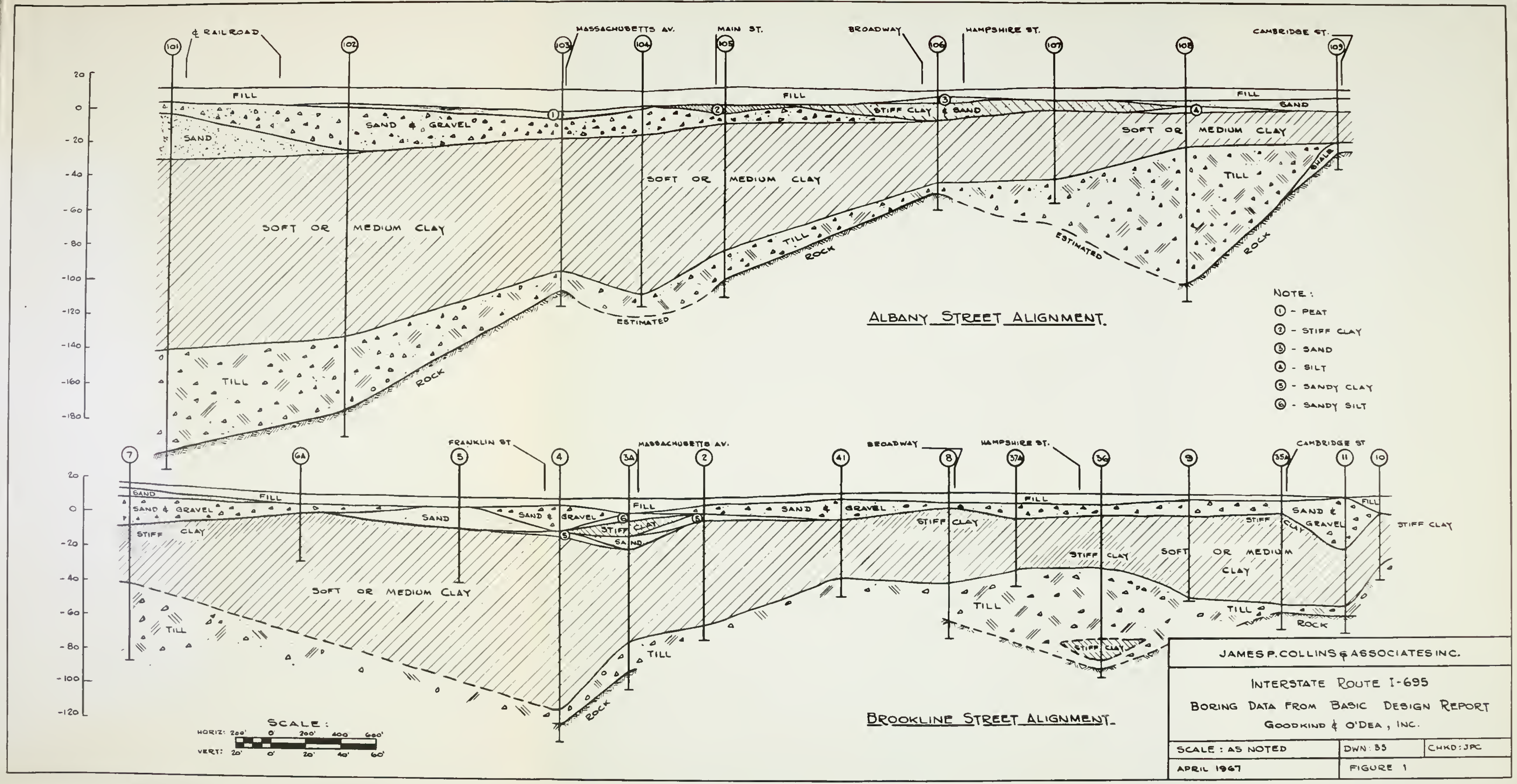
1. Ladd and Luscher, op. cit., fig. 4.9.
2. The M.I.T. report shows estimated strengths for both compression and extension, reflecting the observation that the undrained strength should be dependent on the orientation of the failure plane. Curve (a) is an average of the M.I.T. estimates.

computed factor of safety is almost directly proportional to the strength used for the clay (the miscellaneous surface materials contribute only a small percentage of the shearing resistance). As a consequence, uncertainties in the shear strength result in uncertainties of comparable percentage in the computed factor of safety. While the strengths shown in curve (a) are believed to be the best available estimates, these values are rarely confirmed by conventional soil testing procedures, which generally yield values only 1/2 to 2/3 as large. This is especially true for the normally consolidated clay, and is probably due in large part to sample disturbance.

Usual design practice is to use the results of conventional tests without correction and to design for a safety factor of about 1.4. If conventional test results are assumed to be no higher in the average than 2/3 of the Ladd-Luscher strengths, the corresponding safety factor is 1.0, much less than 1.4. Alternatively, the M.I.T. values might be used for design, but the acceptable factor of safety should be raised to 1.8-2.0. Although by a smaller percentage, the computed value of 1.5 is still less than the design criterion.

The plot of F.S. versus depth of the trial circle for strength distribution (a) shows that the factor of safety decreases steadily with deeper trial circles down to the bottom of the overconsolidated clay. The factor of safety is less than 1.8 for all trial circles below about elevation -50.

The same plot also shows that the factor of safety increases abruptly for circles drawn through the lower normally consolidated clay. This indicates that the computed factor of safety based on the M.I.T. estimates of



ALBANY STREET ALIGNMENT
℄ RAILROAD
MASSACHUSETTS AV.
MAIN ST.
BROADWAY
HAMPSHIRE ST.
CAMBRIDGE ST.
101
102
103
104
105
106
107
108
109
FILL
SAND
SAND & GRAVEL
STIFF CLAY & SAND
SOFT OR MEDIUM CLAY
TILL
ROCK
SHALE
ESTIMATED
NOTE:
① - PEAT
② - STIFF CLAY
③ - SAND
④ - SILT
⑤ - SANDY CLAY
⑥ - SANDY SILT
BROOKLINE STREET ALIGNMENT
FRANKLIN ST.
MASSACHUSETTS AV.
BROADWAY
HAMPSHIRE ST.
CAMBRIDGE ST
7
6A
5
4
3A
2
41
8
37A
36
9
35A
11
10
SAND
FILL
SAND & GRAVEL
STIFF CLAY
SOFT OR MEDIUM CLAY
SOFT OR MEDIUM CLAY
TILL
ROCK
SCALE:
HORIZ: 200' 0' 200' 400 600'
VERT: 20' 0' 20' 40' 60'
20
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
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INTERSTATE ROUTE I-695
BORING DATA FROM BASIC DESIGN REPORT
GOODKIND & O'DEA, INC.
SCALE: AS NOTED
DWN: BS
CHKD: JPC
APRIL 1967
FIGURE 1

strength is independent of the presence of the deep normally consolidated clay because the failure surface will be confined in the material above the elevation where the strength of the clay has its minimum value. This conclusion is independent of the absolute magnitudes of the strengths; it only requires the relative variation in strength with depth shown in curve (a).

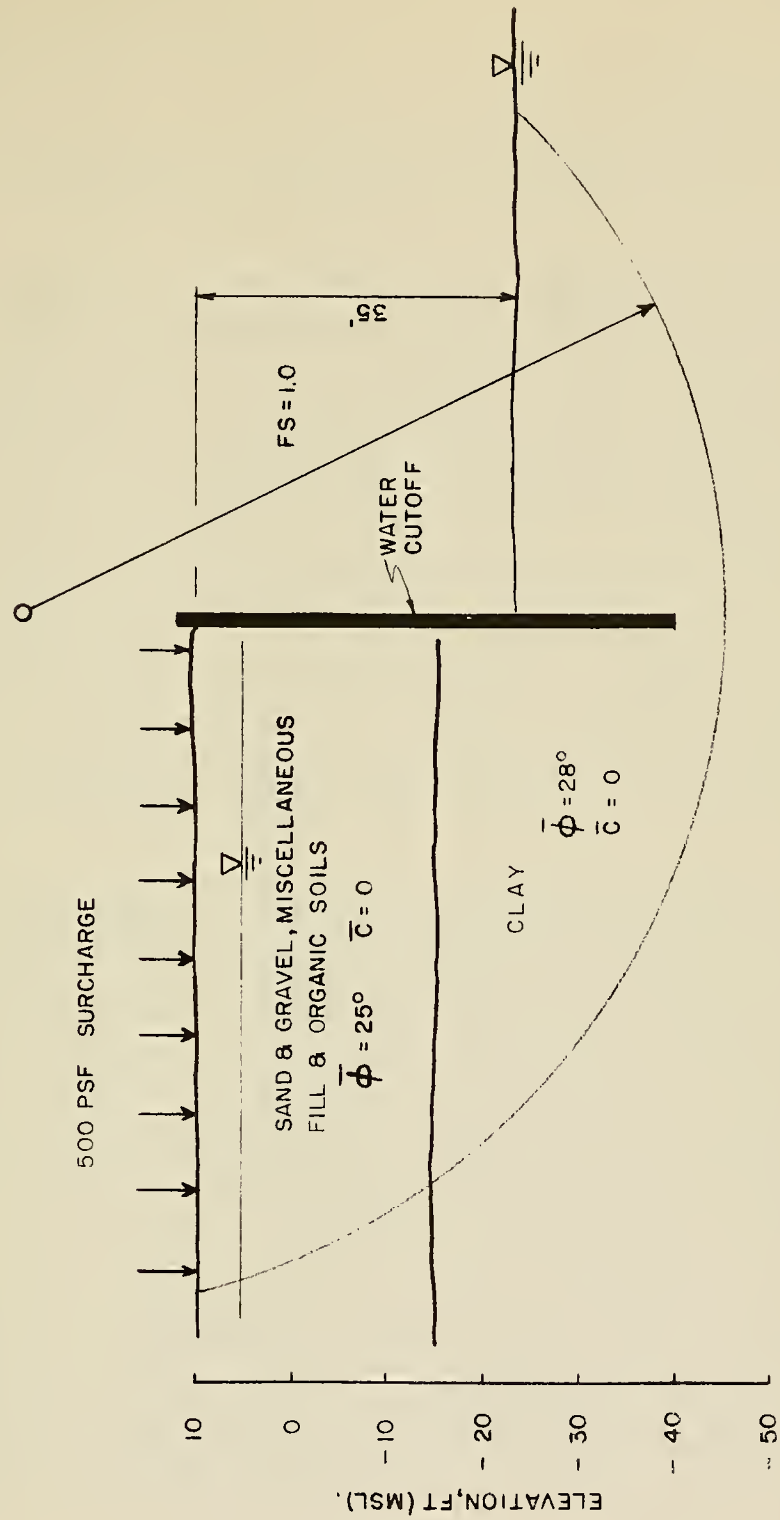
Even if the strength of the normally consolidated clay should not increase with depth, the factor of safety changes very little. This is demonstrated on figure 2-1 by the results of stability analyses using strength distributions (b) and (c). With (b), the normally consolidated clay is assumed to have a strength constant with depth, an assumption in common use by designers. Although this assumption forces (mathematically) the critical failure surface deep into the normally consolidated clay, the computed factor of safety is still 1.45, a decrease of only 5%. The factors of safety for non-critical trial circles passing only through the upper overconsolidated portion are of course identical to case (a). By using a slight decrease of strength with depth in the normally consolidated clay as shown by (c) on figure 2-1, an unlikely case, the critical failure surface can be forced to its greatest possible depth. But the factor of safety is decreased only about 8% to about 1.4.

In summary, these computations lead to the following conclusions for the proposed Albany Street alignment. The roadway excavation cannot be opened to its full width and depth without unacceptably high risk of immediate deep shear failure wherever the underlying clay is deeper than elevation -50. This includes the entire southern half of the alignment between the Charles River and Cambridge Street (figure 1). Depths of clay below -75 have no important

bearing on the factor of safety. Consequently, the meaningful measure of the relative feasibility of the alignment (as far as stability of the excavation is concerned) is the length of the route which passes over clay deposits shallower than -75. The maximum depth encountered is insignificant.

Unfortunately, the factor of safety for the excavation shown on figure 2-1 will decrease with time. The clay below the cut will absorb water and swell, which will decrease its strength. The limiting case is illustrated by a long-term analysis in which it is assumed that all excess pore pressures in the clay have dissipated, leaving the soil with only frictional shearing resistance. A trial failure circle is shown on figure 2-2 that has a factor of safety of 1.0 using a frictional resistance in the clay of 28^{o} with the water table at the elevations shown. The factor of safety for this circle immediately after excavation would be about 3. The time required for the decrease from 3 to 1 is very difficult to estimate because it is greatly affected by minor details in the soil profile and by various other uncertainties such as rainfall. No difficulties would be expected for a construction period of a month or two; leaving the cut open for longer periods would be increasingly hazardous.

The implications in judging the feasibility of the Albany Street alignment are that a second mode of shear failure along a shallow circle is possible if the excavation is allowed to stand open for more than a month or two. Since the risk of failure is a function of time, it is more a matter of judgment than of analysis. At the very least, the construction would be critically vulnerable to strikes, bad weather, and other common but unpredictable delays. Because such a failure might well be catastrophic along the Albany Street corridor,



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I-695 ALBANY STREET ALIGNMENT

LONG TERM STABILITY ANALYSIS

FOR GRAVITY SLAB (BOAT SECTION)

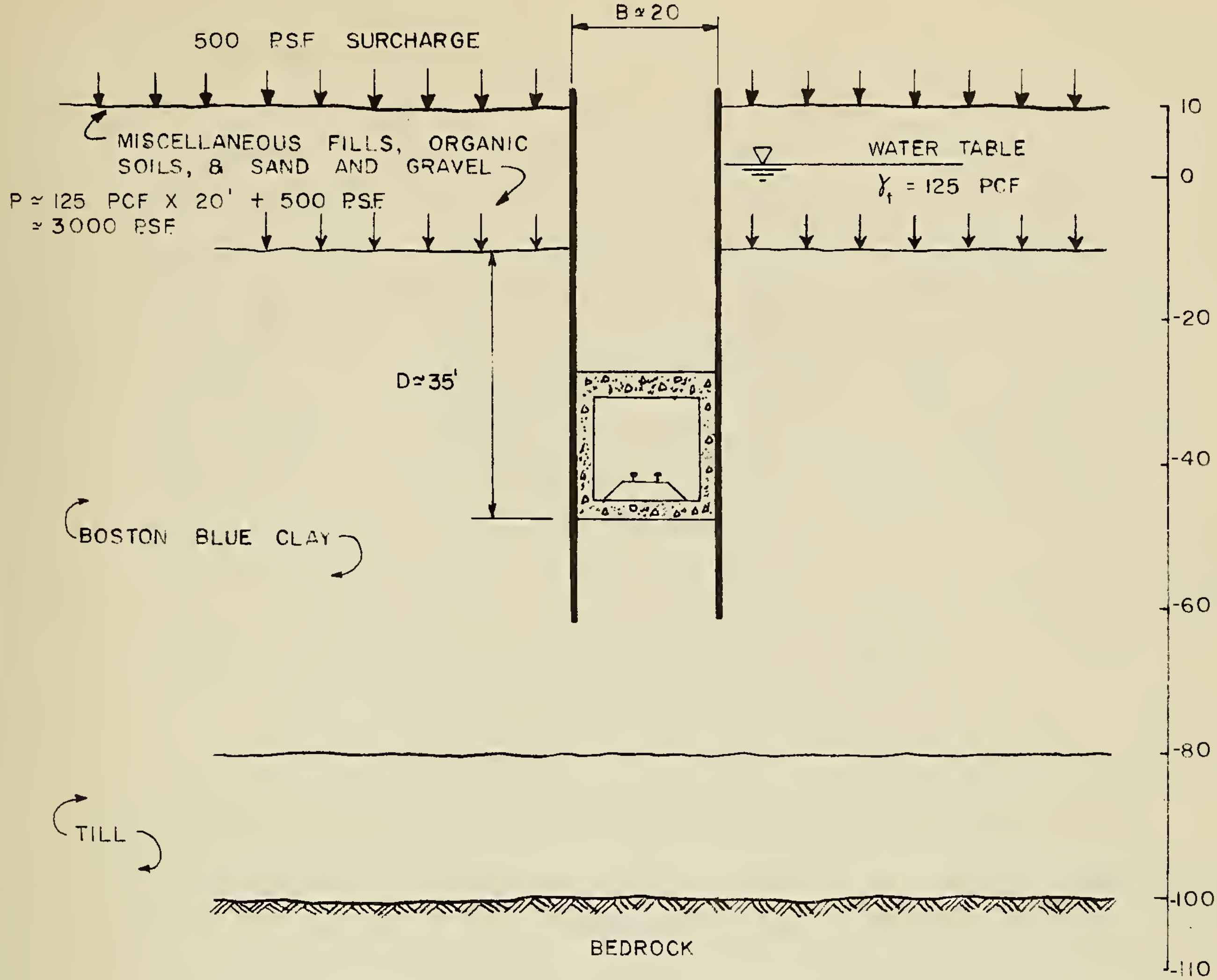
SCALE: AS NOTED	DWN : BS	CHKD : JPC
APRIL 1967	FIGURE 2-2	

it is recommended that the risk not be taken. A design can be adopted which eliminates the problem.

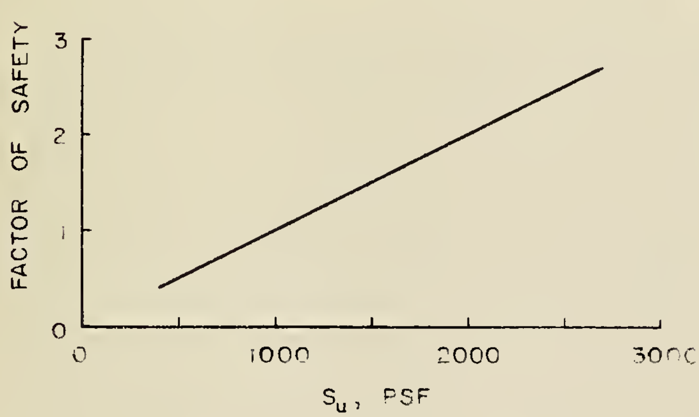
The cut for the M.B.T.A. realignment can be analyzed with bearing capacity formulas as shown on figure 2-3. Again, the situation is one where the factor of safety is proportional to undrained strength and will decrease with time. With the Ladd-Luscher strengths shown on figure 2-1, the factor of safety for the M.B.T.A. cut immediately after excavation should be about 1.3, somewhat less than the recommended 1.8. If 2/3 of these values are again taken as an estimate of the conventional test results, the safety factor is only about 0.9. Since even these safety factors will decrease with time, the probability of a failure is clearly far too high to justify open cut construction.

The technical analyses presented above can now be summarized. Three separate modes of failure have been identified, all of which are likely under appropriate circumstances: an immediate deep shear failure if the bottom of the clay deposit is below -50; a shallower failure, which becomes increasingly likely as the excavation is allowed to remain open; and finally, an almost inevitable failure at the bottom of the excavation for the M.B.T.A. realignment. In summary, based on data so far available, and if conventional design and construction must be used, it is impossible to build this highway on the alignment and profile presently proposed for the Albany Street corridor without intolerable risks of disastrous failure over much of its length.

There are, however, a number of unconventional design concepts and construction methods which eliminate or minimize the risks of these three types of failure. Again considering the roadway excavations first, it is apparent that the factor



$$FS = \frac{N_c \cdot S_u}{\gamma_t D + P} \qquad FS = \frac{6.7 \cdot S_u}{125 \cdot 35 + 3000} \simeq S_u/1000$$



S_u IS THE AVERAGE UNDRAINED SHEAR STRENGTH WITHIN A DEPTH 20' BELOW THE BOTTOM OF THE CUT

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I-695 ALBANY ST. ALIGNMENT
MBTA CUT AT MAIN ST, CAMBRIDGE

SCALE: AS NOTED	DWN.: B.S.	CHKD.: JPC
APRIL 1967	FIGURE 2-3	

FORM NO. 15A-68

of safety for slope stability in any mode will be increased if the depth of the excavation is reduced. It follows, therefore, that if the roadway slab can be anchored down, rather than relying on its own weight to resist hydrostatic pressures, its thickness can be reduced from 12 feet to 2 or 3 feet. This would permit the depth of the excavation to be reduced from 35 to 26 or 27 feet in most places and no more than 30 feet anywhere. Moreover if the anchors are grouted into the rock and prestressed, the effective stresses in the clay at the toe of the sheeting can be restored to the pre-excavation levels. This would further increase the factor of safety and reduce its dependency on time.

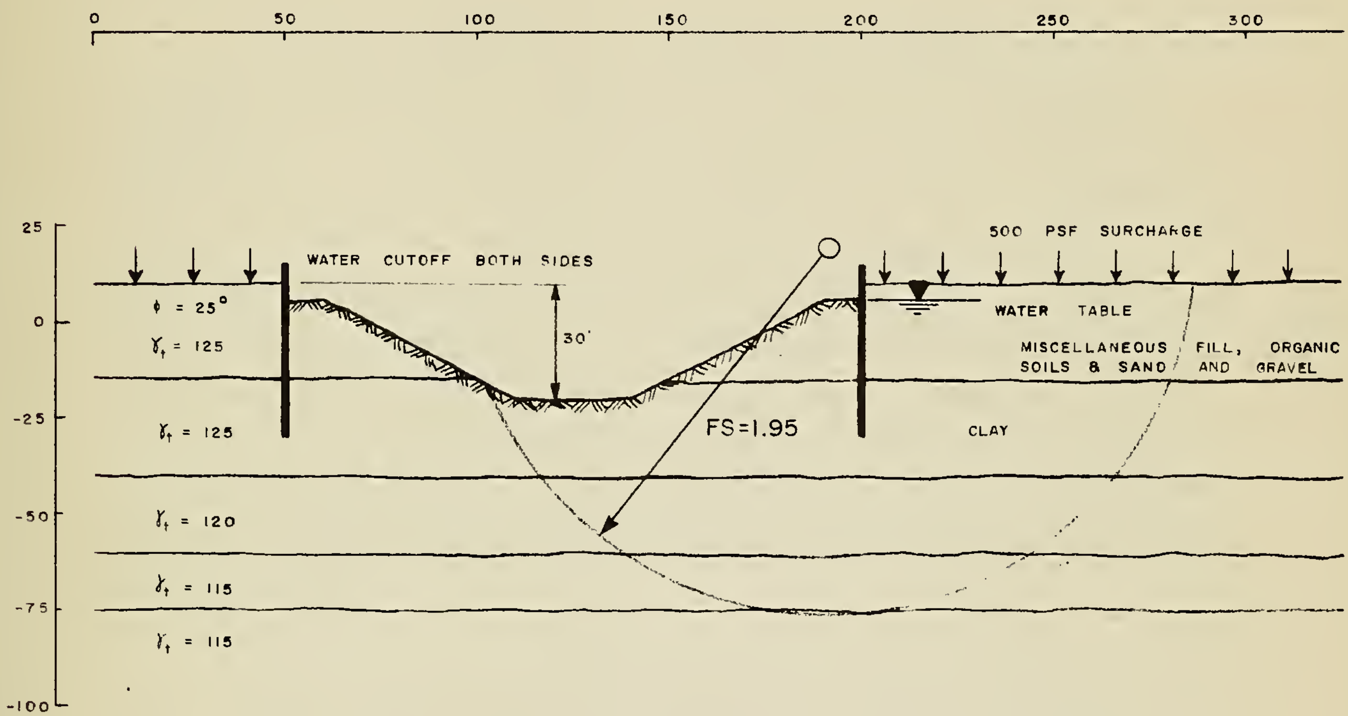
Prestressed anchors grouted into rock sockets have been in common use for many years. They are widely used in building excavations for lateral restraint of sheeting or basement walls. Their principal advantage in this application is that they permit the elimination of interior bracing. They are described as unconventional here only because they have not seen wide application in highway construction.

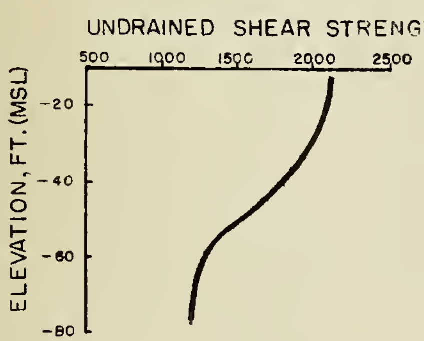
The prestressed anchors have a number of advantages over anchor piles. First, they are probably less expensive. Secondly, their load carrying capacity is not related to the properties of the soil through which they pass, and in particular, the changes in those properties with time. Thirdly, because they are prestressed, each anchor in effect is tested to a substantial overload before use. Because of these latter two factors, the prestressed anchors eliminate most of the shortcomings commonly objected to in anchor piles. Finally, in this application, the anchors are far more effective in restoring the effective stresses of the clay and hence in increasing the safety factor against shallow long term failure.

Because of the problem of a longer term failure on a shallow circle, prestressed anchors are not in themselves a complete answer. It is still necessary to devise a construction procedure which will maintain the factor of safety between the time the excavation is opened and the anchor slab is completely in place. It should be noted that a retaining wall is not an adequate solution; the failure surface is deep enough to pass completely under such construction.

One possibility is the construction sequence shown at its most critical stage in figure 2-4. After installation of the watertight barriers, the excavation is opened in the middle third, with berms left in place on the outside edges. For the critical trial surface a factor of safety of about 2.0 has been computed using the Ladd-Luscher shear strength values. Again the factor of safety will decrease with time; however an excess of 0.2 is available before the marginal value of 1.8 is reached. Moreover the pore pressures at the level of the bottom of the excavation will decrease more slowly because of a longer drainage path than would be the case if the excavation were opened completely. After the anchored slab has been constructed along the center strip, the remainder of the slab can be installed after removal of the berm. It may be necessary to remove the berm and place the slab in more than one step on each side of the center strip in order to keep the safety factor adequately high.

The bedrock along much of the Albany Street alignment is a very soft fractured siltstone (see Section II). There is no experience available on which to base a judgment of the capacity of this rock as a reaction for prestressed anchors. It is strongly recommended, therefore, that a field





NOTE

STRENGTH VALUES FROM : "ENGINEERING PROPERTIES OF THE SOILS UNDERLYING M.I.T. CAMPUS" BY C.C. LADD & U. LUSCHER FIG. 4.9.

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I-695 ALBANY STREET ALIGNMENT

SHORT TERM STABILITY ANALYSIS

FOR ANCHORED SLAB

SCALE : AS NOTED	DWN. : B.S.	CHKD. : JPC
APRIL 1967	FIGURE 2-4	

program be carried out to evaluate this capacity before the concept is used in final design. However, the principal uncertainty is the depth of rock socket which will be required to develop the full capacity of the anchors; there is nothing inherent in the concept which should prohibit its serious consideration.

A second possibility, which is more conventional but almost certainly more expensive, is the use of partial excavation. If the excavation which is open at any one time is limited in horizontal dimensions, the factor of safety can be kept sufficiently high. However, this possibility should be approached with caution. Careful examination of figures 2-1 and 2-2 shows that the failure surface emerges from the bottom of the excavation at the center line or in the near half of the excavation. Consequently the factor of safety for either mode of failure will be substantially unaffected if the excavation is done by halves.

The situation is improved, but is still marginal, if the center third of the excavation is completed but with berms left on both sides. The safety factor of about 2.0 arrived at for the geometry shown in figure 2-4 will be reduced to 1.8 if the depth of the excavation is increased to 35 feet for a gravity slab. The short term strength is barely adequate, and since again the safety factor will decrease with time, the longer term stability remains questionable.

It would appear therefore that if a gravity slab is to be used with a conventional boat section, partial excavation is a solution to the stability problem only if it is used in a "checkerboard" fashion. In this procedure, the plan

area of the excavation is divided into squares and diagonally alternate squares excavated one at a time. The excavation is carried to its full depth and the slab placed at the bottom before the adjacent excavations are opened.

While this solution is technically feasible, it is apparent that it is extremely slow and costly. The spoil must be removed vertically between extensive bracing systems by clamshell bucket or similar crane supported equipment. The cost of excavation done this way has been estimated in the main body of the report to which this study is appended. It is sufficient to note here that it is two to three times as expensive and at least that much slower than techniques more suitable to the scale of highway construction.

There are long sections of the Albany Street alignment where the bottom of the clay is above elevation -50. For these portions of the route, the deep immediate shear failure is not of great concern. The problem of the longer term shallow failure remains. One solution for these sections might be the segmental construction suggested in connection with the problem of maintaining the water table discussed in Section V. A. A construction sequence was proposed in which short sections of the highway were excavated and the boat section quickly constructed. All further construction on that section was then completed during the summer months. The object was to draw down the water table for a period of only a few months in each year.

The problem shown in figure 2-2 assumes the water table is continuously maintained on the outside of the excavation. If instead the water table is allowed to fall during construction, the factor of safety in this mode of failure is increased to well above 2.0 and the problem is eliminated.

There is little that can be said about the excavation for the M.B.T.A. realignment. On the basis of the data available to date, the probability of a shear failure is so high that cut-and-cover construction should not be seriously considered and tunneling methods will have to be resorted to. Because of the stiff roof clays, liner plate methods are probably adequate, especially if the adjacent buildings are underpinned to sufficient depth. However this problem has not been examined in detail, and it may prove necessary to drive a shield or use another of the more expensive tunneling methods.

C. Protection of Existing Structures

The investigation summarized in Section IV revealed 32 buildings close enough to the proposed alignment to require some form of protective construction. Of these 32 buildings, the most important are summarized in Table 1. The remainder are generally 1-story light industrial buildings of uncertain age and marginal construction.

During the excavation of the roadway excavations, the sheeting or other structural restraints will yield slightly as the lateral earth pressures develop. In this study, a building was considered to require protective construction if some or all of its foundation elements lay within the zone of soil likely to be affected by this yielding. The horizontal movement of the boundary of the yield zone will cause a vertical movement of the soil as well, and hence result in settlement of any building founded within the zone. Consequently, protective construction generally will be some form of underpinning to provide vertical support.

It should be emphasized that if underpinning is indicated

for any particular building there is no safe way to avoid it. The settlement (or "loss of ground" in construction parlance) accompanying a deep excavation may be as much as 3 to 6 inches, especially where the excavation must be made partly in cohesionless soils below the water table. Settlements of this magnitude are sufficient to cause severe structural distress in almost any building. For the most part the soil movements have their seat in minor misalignment of the sheet piles and the supporting wales and braces, rather than the structural deflections of these members. The magnitudes of these movements are greatly dependent on the care and skill with which the various structural members are installed and stressed. As a practical matter some loss of ground is unavoidable with any conventional method of sheeting and bracing, even when installed by skilled and experienced specialists. It can be concluded, therefore, that conventional sheeting is not ordinarily a substitute for underpinning.

There is one important exception to this rule. The slurry trench wall has been suggested as a method of controlling groundwater in Section A above. The slurry wall has also been successful in controlling the settlement of buildings adjacent to deep excavations. There are a number of reasons for this success. First, unlike sheet piles or breastboards, the wall is in intimate contact with the soil behind it and is continuous without minor openings. Secondly, a slurry trench wall some 2 feet thick is substantially stiffer than a sheet pile wall, even if heavy Z-sheets are used. Finally, the space between the wales and the wall can be packed with dry mortar to obtain a uniform bearing across the entire length of the wall. The aggregate effect is to eliminate most of the small accidental movements which normally cause settlement of the

soil behind.

Experience with the excavation within a slurry trench wall at 180 Beacon Street is revealing here. The slurry trench wall on the east side of the excavation was made within 6 inches of the foundations of a ten story apartment building at 172 Beacon Street. This building has a steel frame and a brick facia, and is founded on timber piles driven to the sand and gravel stratum. At this location that stratum is only about 4 feet thick. This is a marginal foundation design by modern standards, but apparently had performed adequately.

Very careful settlement observations were made on this building. A benchmark was installed to rock as a permanent reference and 16 settlement observation points were installed on columns throughout the basement. Observations were made with a flexible water tube, and individual observations are believed to be accurate to 0.02 inches. Settlement observations were made at an average frequency of once per week from August 1964, when construction of the slurry wall at 180 Beacon Street was started, to April 1966. At that time the wall was complete, the piles had been driven, and the substructure and twelve stories of the new superstructure were in place.

The total settlement of 172 Beacon Street amounted to about 1/2 inch. Moreover, the settlements were unexpectedly uniform with no significant variation between the sides of the building adjacent to, and opposite to, the excavation at 180 Beacon Street. This pattern of settlement suggests very strongly that what movement did occur was entirely attributable to strains accompanying deep seated shear stress in the underlying soft clay; that is, stresses similar to

those described above in the discussion of the stability of deep excavations. In this respect, this slurry trench wall has been completely successful; not so much as a plaster crack has been reported in the way of damage to 172 Beacon Street.

Despite these apparent capabilities however, it would be inappropriate in this preliminary study to conclude that this unusual construction will be used in final design, or even seriously considered. Consequently, it has been necessary to base this underpinning study on the assumption that a more conventional construction technique will be used.

Many factors which can be known only approximately at the date of this report (April 1967) will affect the need and cost of underpinning. The alignment is still tentative and in any event known only with the accuracy of the 1" = 100' print on which this study is based. Foundation information is sketchy for many of the buildings involved and cannot be known without the exhaustive field investigations appropriate to final design. Finally, the highway cross-section and construction methods must be considered.

Of these factors, the first two -- the final alignment and information on the existing foundations -- are relatively unimportant. Over most of its length, the alignment can be changed slightly without greating changing costs; an increase in the underpinning required on one side is likely to be offset by a decrease in the other. The study of existing foundations reported in Section III confirmed the near-universal practice of founding all but the largest buildings on the sand stratum, the elevation of which is known with fair accuracy. The overconsolidated clay beneath it is an adequate bearing stratum for small and moderate foundations

and it can be assumed most underpinning will be carried into that material. Underpinning would generally proceed downward from the base of existing columns or pile caps, and the elevations of these can be estimated closely enough from the elevations of the existing basement floors. In general, therefore, the required depth and capacity of underpinning can be estimated without detailed information on foundation construction.

The remaining factor however -- highway cross-section and construction methods -- has a major influence on the cost of underpinning. Both the extent and depth of underpinning will be reduced if an anchored slab is used rather than a full "boat" section. As pointed out above, the requirements for underpinning will be drastically reduced if a slurry trench wall is used.

In studying the various buildings which appear to require underpinning for this alignment, it has become apparent that it is almost impossible to generalize about the underpinning techniques which ought to be used in this area. The decision will vary with each building and in some cases from column to column. Detailed recommendations for each building will have to be deferred until final design. Some techniques which have been considered are caissons dewatered with outside wellpoints; jacked piles; and under-floor needle beams supported on caissons, jacked piles, or driven piles outside the building. In some cases, the building may be supported in part on soldier piles installed as part of the highway excavation.

It would appear, however, that most of the appropriate methods have a common unit price of $0.60 to $0.80 if reduced to units of dollars per ton supported per foot of depth.

That is, a 100 ton column load which must be underpinned to a depth of 20 feet will require an expenditure of $1200 to $1600 regardless of the method of underpinning. This observation permits an estimate with fair accuracy of the total cost of protective construction for this alignment. Using an average value of $0.70 per ton of capacity per ton of depth, and allowing a 20% contingency, the total cost of underpinning along the proposed Albany Street alignment is $1,460,000.

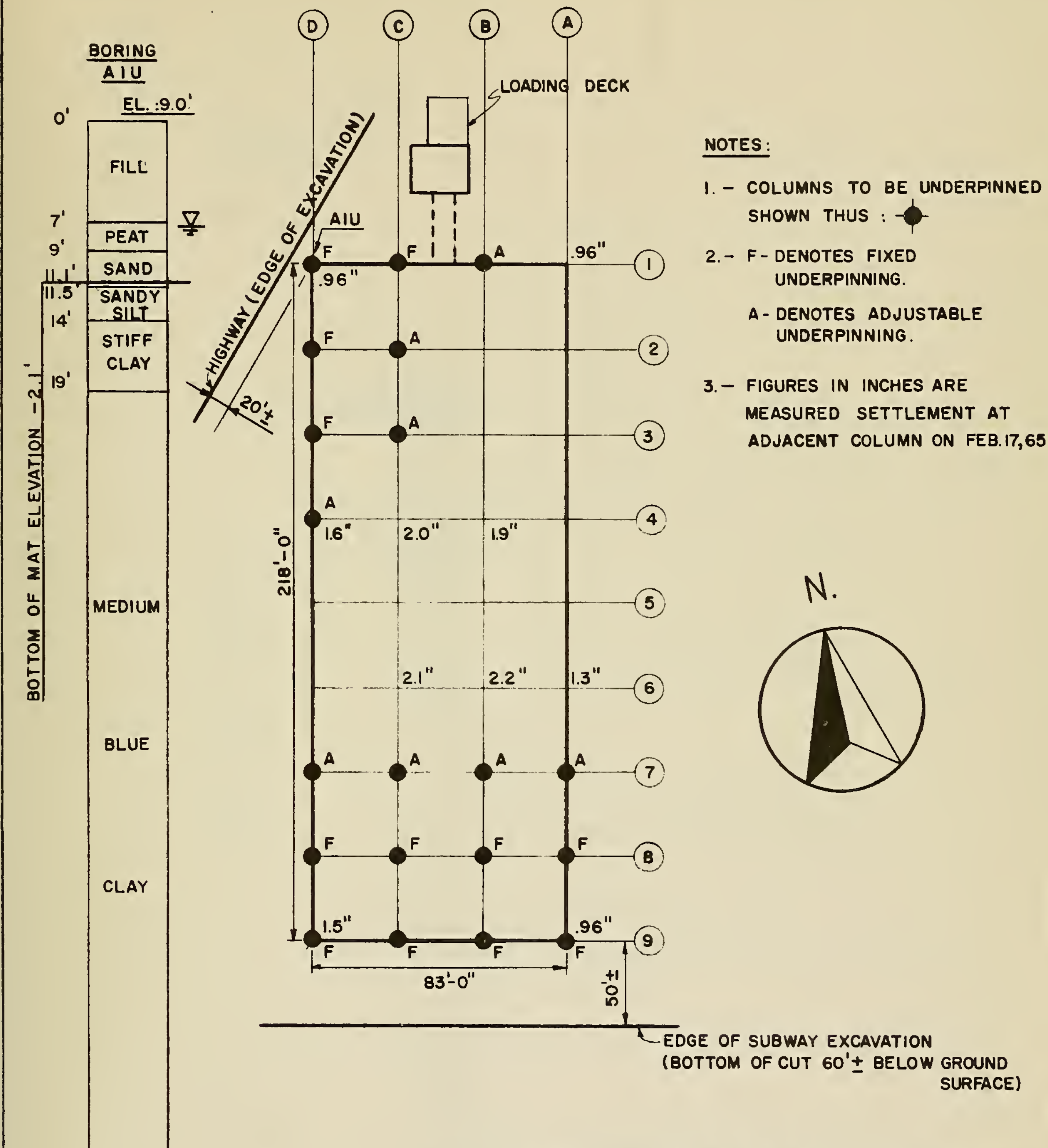
That figure is intended to be a conservative and defensible estimate which is based on a number of assumptions which may be optimistic after detailed design study. For example, it has been assumed that the Alpha Building at Technology Square will require underpinning only in part. This building is discussed in detail below; it will be seen that probable future settlements may require that the entire building be underpinned. It seems unlikely on the basis of information available to date that underpinning costs for the Albany Street alignment will be less than $1,200,000. If conventional construction is used, it might conceivably amount to $2,500,000 or even $3,000,000, depending on the final alignment and detailed design investigations.

If a slurry trench wall and anchored slab are used in the highway cross-section, underpinning costs might be reduced to $500,000. In this event the only major building requiring underpinning is the Alpha Building at Technology Square. This building is simply too large, heavy, and expensive to warrant attempting the highway construction without first underpinning it, even if a slurry trench wall is used. It must also be protected from earth movements arising from the M.B.T.A. tunnel construction.

Underpinning is not a common procedure in highway construction and the design and construction techniques may be unfamiliar. To illustrate the difficulties and risks of this work, a detailed study has been made of the underpinning required for Building Alpha in Technology Square. This building was chosen as an example because it is one of the few buildings which will require underpinning for almost any conceivable alignment within the Albany Street corridor, and for which detailed structural, foundation, and soils information is available. Figure 3-1 shows the geometrical relationship in plan between the columns of Alpha Building and the proposed excavations for the highway and the M.B.T.A. tunnel. The same figure also shows a typical boring log at this site.

The first step in designing the underpinning for Building Alpha was to establish the depth and extent to which underpinning would be required. In this case, the depth could be arrived at by inspection. All underpinning must be carried down to the glacial till in the vicinity of elevation -60. There is no suitable bearing stratum for a building of this size at any lesser depth.

The horizontal extent of the underpinning is arrived at by considering the differential settlement which the building will undergo during and after underpinning, and comparison of that with the differential settlement which the building can probably tolerate without extensive interior damage. The settlement which the building had undergone by February 1965 (3 years after construction) is shown in figure 3-1. The settlement at the perimeter of the building, 1 to 1.5 inches, is believed to be substantially complete. However, the settlement in the interior is expected ultimately to reach 2.7 inches, about 0.5 inches more than had taken place by



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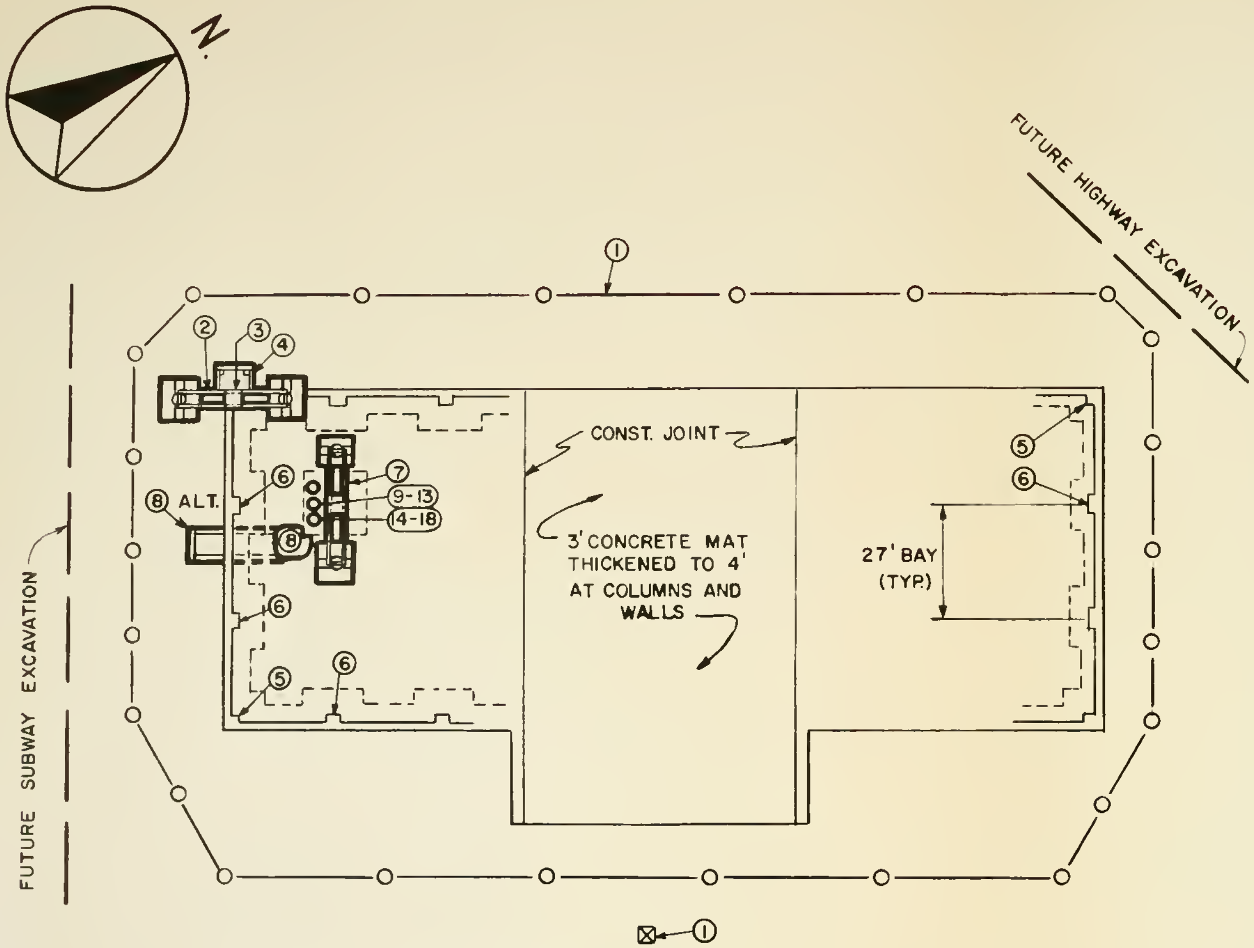
UNDERPINNING – ALPHA BUILDING
TECHNOLOGY SQUARE

COLUMN LAYOUT SHOWING RELATIONSHIP TO PROPOSED EXCAVATION

NO SCALE	DWN : B.S.	CHKD : J.P.C.
APRIL 1967	FIGURE 3-1	



NOS. REFER TO NOTES AT RIGHT.

NOTES:

1. - INSTALL DRAINAGE LINE OR WELL POINTS AROUND BUILDING. INSTALL BENCH MARK TO ROCK.

2 - SUPPORT CORNER COLUMN WITH NEEDLE BEAMS ON JACKS AND TEMPORARY PADS. SEE FIG. 3-3

3. - DIG ACCESS PIT AND SHEETED SHAFT FOR UNDERPINNING CAISSON. FILL WITH CONCRETE AND DRYPACK. SEE FIG. 3-4.

4. - BACKFILL ACCESS PIT AND REPAIR WALLS AND COLUMNS.

5. - REPEAT PHASES 2,3 AND 4 FOR OTHER CORNER COLUMNS.

6 - REPEAT 2,3 AND 4 FOR REMAINDER OF EXTERIOR COLUMNS

7. - SUPPORT INTERIOR COLUMN ON NEEDLE BEAMS ON JACKS AND TEMPORARY PADS.

8. - BREAK ACCESS PIT THROUGH MAT AT EDGE OF INTERIOR FOOTING AND TUNNEL TO CORNER OF FOOTING. INSTALL BREASTBOARDS TO HOLD SIDES OF TUNNEL. SEE FIG. 3-5. ALTERNATIVELY, TUNNEL FROM EDGE OF MAT IF INTERIOR ACCESS IMPOSSIBLE.

9. - JACK 3' SECTION OF 18"d. PIPE PILE DOWN INTO SOIL BELOW FOOTING, USING FOOTING AS REACTION. SEE FIG. 3-5.

10. - RETRACT JACKS, WELD SECOND 3' SECTION OF PIPE TO FIRST AND REJACK.

11. - REPEAT 9 AND 10 UNTIL PILE REACHES DENSE SAND AND GRAVEL AT ABOUT ELEVATION AND JACK LOAD = 150 TONS.

12. - CLEAN OUT PILE AND FILL WITH CONCRETE.

13. - REJACK TO 150 TONS. INSTALL AND WEDGE TEMPORARY STRUT. SEE FIG. 3-5.

14 - EXPAND TUNNEL TO LOCATION OF ADJACENT PILE AND REPEAT 9 THROUGH 13.

15. - REJACK AND REWEDGE FIRST PILE.

16 - REPEAT FOR THIRD PILE AND REJACK AND REWEDGE FIRST TWO.

17 - CONTINUE FOR ENTIRE CLUSTER, REJACKING AND REWEDGING ALL PILES IN TWO ADJACENT ROWS AFTER COMPLETING EACH PILE.

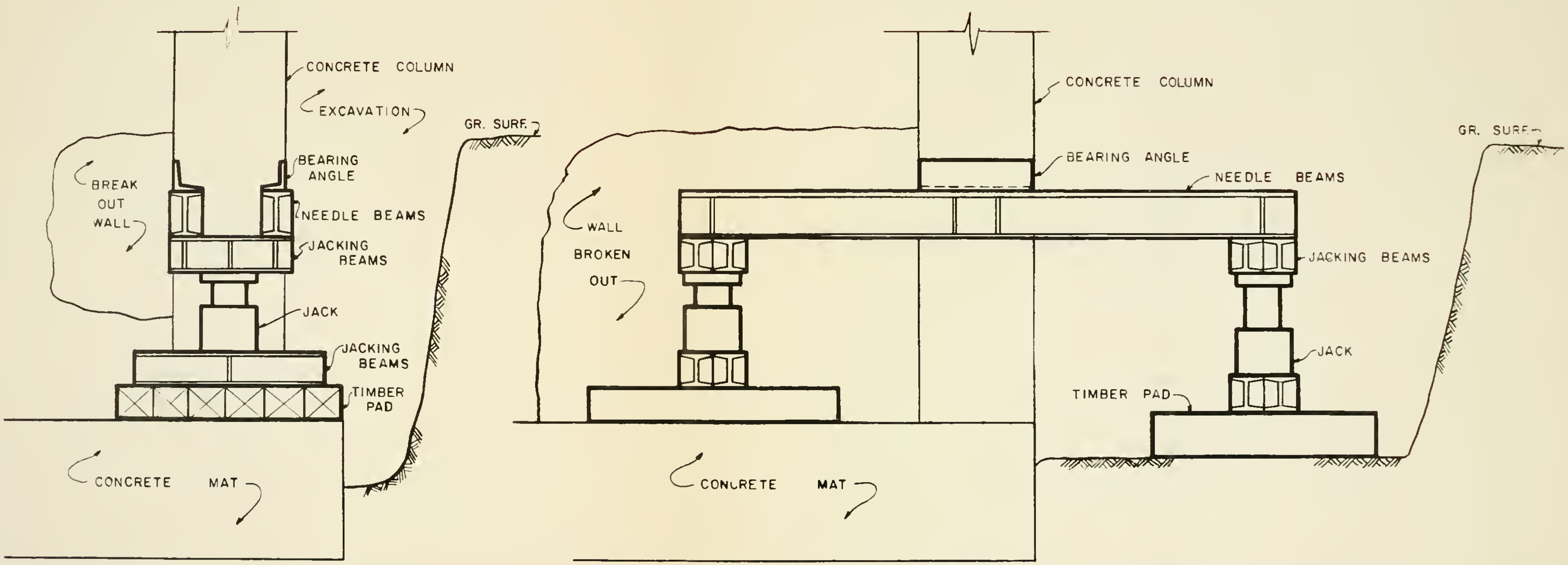
18. - REPEAT STEPS 7 THROUGH 17 FOR ADDITIONAL INTERIOR COLUMNS TO BE UNDERPINNED IN THIS ROW.

NOTES (CONTINUED)

19. - REPEAT AT NEXT ROW OF INTERIOR COLUMNS BUT LOCK JACKS, AND LEAVE IN PLACE FOR FUTURE SMALL ADJUSTMENTS.

20. - COMPLETE REPAIRS, CONSTRUCT PERMANENT CHAMBERS AND ACCESS PANELS AROUND CLUSTERS WHERE JACKS REMAIN, AND FILL OTHER TUNNELS WITH PUMPED CONCRETE.

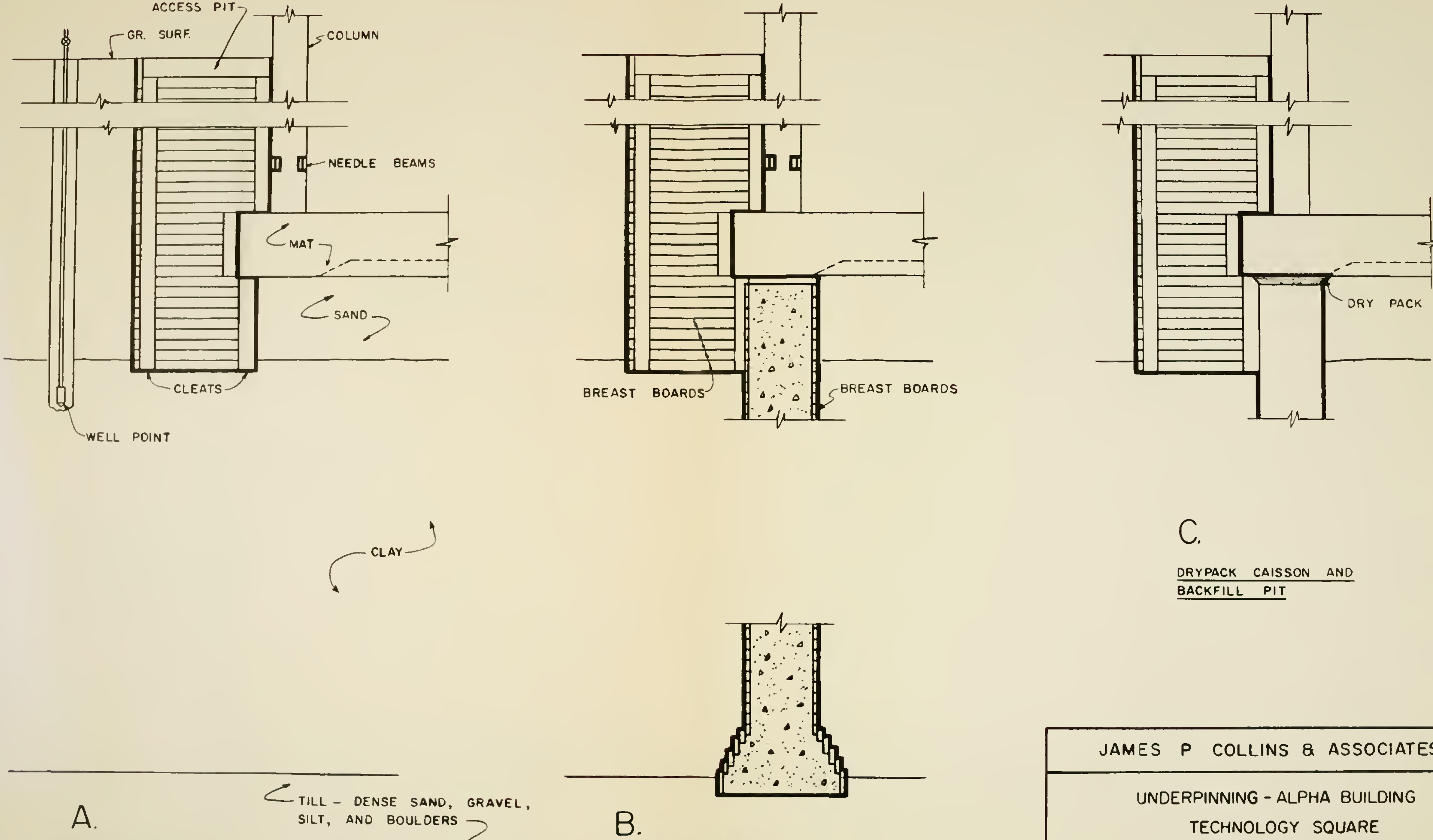
JAMES P. COLLINS & ASSOCIATES INC.		
CONSTRUCTION SEQUENCE UNDERPINNING FOR ALPHA BUILDING TECHNOLOGY SQUARE		
NO SCALE	DWN.: B.S.	CHKD.: J.P.C.
APRIL 1967	FIGURE 3-2	



JAMES P COLLINS & ASSOCIATES INC.

UNDERPINNING - ALPHA BUILDING
TECHNOLOGY SQUARE
SCHEMATIC NEEDLE BEAM INSTALLATION AT
CORNER COLUMN OTHER COLUMNS SIMILAR

NO SCALE	DWN. : R.S.	CHKD. : J.P.C.
APRIL 1967	FIGURE 3-3	



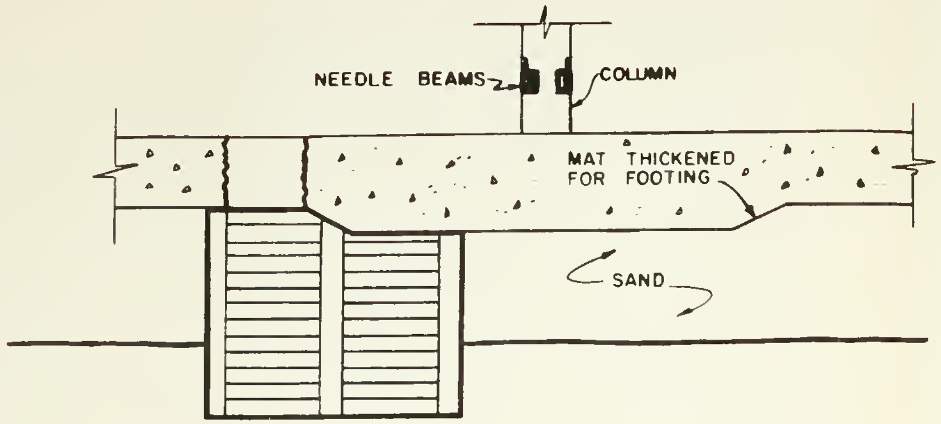
A.
INSTALL ACCESS PIT

B.
DIG CAISSON AND FILL WITH CONCRETE

SEE FIGURE 3-2

C.
DRYPACK CAISSON AND BACKFILL PIT

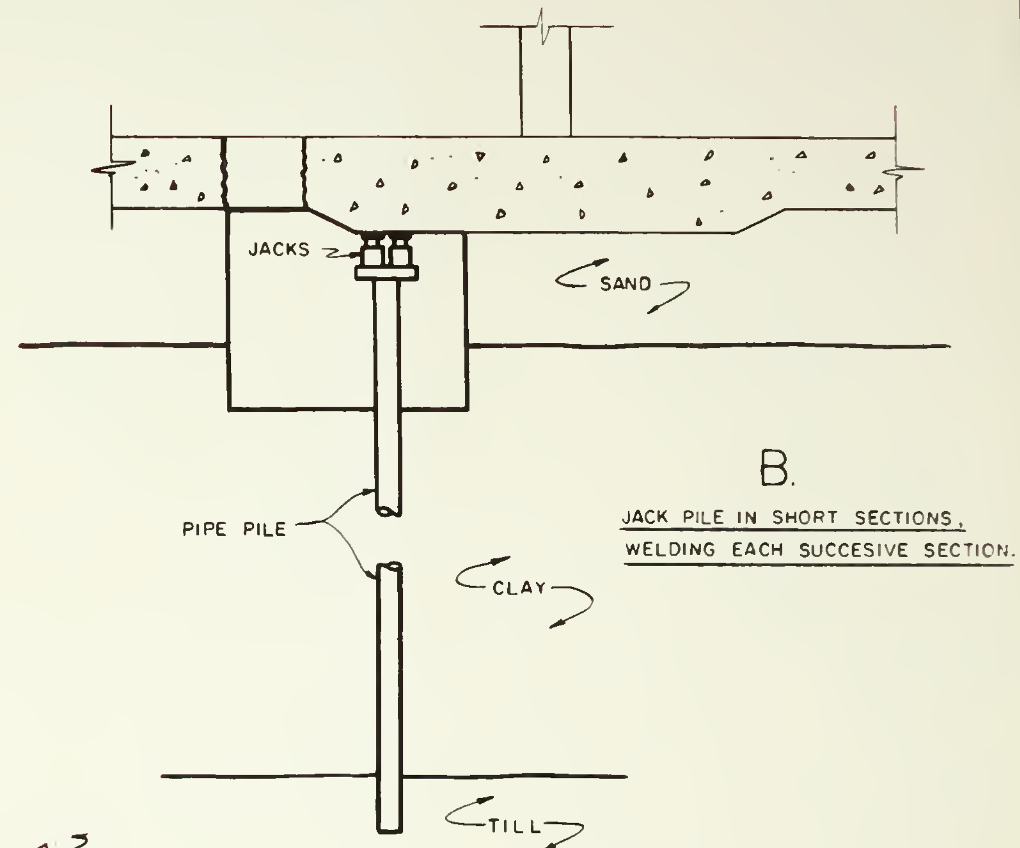
JAMES P COLLINS & ASSOCIATES INC	
UNDERPINNING - ALPHA BUILDING TECHNOLOGY SQUARE CAISSON CONSTRUCTION	
NO SCALE	DWN: BS & WJS — CHKD: JPC
APRIL 1967	FIGURE 3-4



A.

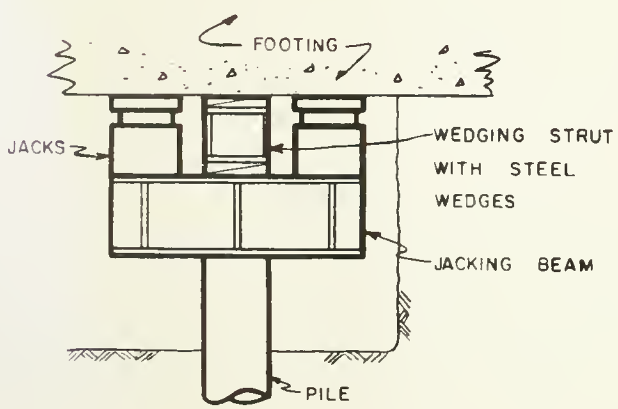
BREAK OUT SLAB AND TUNNEL TO CORNER OF FOOTING

BREASTBOARDS NOT SHOWN IN SUCCEEDING SKETCHES



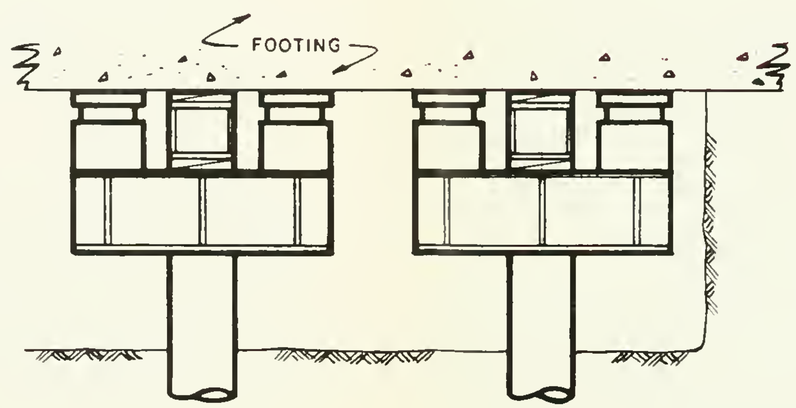
B.

JACK PILE IN SHORT SECTIONS, WELDING EACH SUCCESIVE SECTION.



C.

CLEAN OUT PILE, FILL WITH CONCRETE AND RELOAD TO 150 % OF CAPACITY. INSERT WEDGING STRUT TO HOLD LOAD.



D.

REPEAT FOR ADJACENT PILE, THEN REJACK AND REWEDGE FIRST PILE.

SEE NOTES, FIG 3-2

JAMES P. COLLINS & ASSOCIATES INC.	
UNDERPINNING – ALPHA BUILDING TECHNOLOGY SQUARE INSTALLATION OF JACKED PILES UNDER INTERIOR COLUMNS	
NO SCALE	DWN: BS & WJS / CHKD · J.P.C.
APRIL 1967	FIGURE 3-5

February 1965. Thus the maximum differential settlement measured to date is 1.2 inches, with 1.7 inches ultimately expected. From the uniform pattern of the settlements, it is reasonable to suppose that this differential will take place across the width of 2 bays. Thus if no changes are made in the foundations, an ultimate differential settlement of the order of 1 inch can be expected between two adjacent columns in the exterior bays and 0.7 to 0.8 inches between two interior columns. Present maximum differential settlements are probably about 0.7 inches across the exterior bays and 0.6 inches between the second and third rows of columns.

To assess the effects of underpinning, assume that an exterior column does not settle at all (i.e., is perfectly underpinned), while the adjacent column settles 0.5 inch. The differential settlement would then be about 1.2 inches across that exterior bay. If a column in the second (first interior) row were perfectly underpinned, it would undergo no further settlement. The adjacent column in the third row would settle an additional 0.5 inches, so that the ultimate differential settlement would amount to about 1.1 inches across that bay.

Actually, no underpinning is perfect. Settlements are more likely in practice to range between 0.5 and 1.0 inches if meticulous care and the highest workmanship are exercised. It would appear, however, that if that great care is used, differential settlements can be limited to about 1.2 inches.

The building appears to be able to tolerate differential settlements of about the same order of magnitude. An empirical design standard that is sometimes used says that buildings risk extensive damage to interior finish if the differential settlement between adjacent columns is allowed to exceed a

1/300th of the span, for this building about 1.1 inches. A structurally dangerous differential settlement would be of the order of 2 inches, depending on the pattern of the deflections.

It is concluded that if the underpinning is very carefully done, the probable differential settlement, 1.2 inches, will be tolerable. For this preliminary study, it has been concluded that partial underpinning will be satisfactory if all of the columns within the zone of soil likely to be influenced by the excavation are underpinned permanently and the next adjacent columns are underpinned so as to permit later small adjustments in elevation. This will permit the differential settlements to be spread across 2 bays. Physically it would be accomplished by leaving jacks locked but in place. The columns requiring fixed and adjustable underpinning are shown in figure 3-1.

Building Alpha is founded on a continuous concrete mat which for the most part bears on the sand and gravel stratum. Local pockets of organic silt have been removed and replaced with compacted gravel to allow a uniform bearing elevation. The mat is 4 feet thick under columns and walls and 3 feet thick elsewhere. The bottom of the thickened portion in relation to the soil profile is also shown in figure 3-1.

A number of underpinning procedures have been considered for the foundation design and soil conditions encountered here. In balance, the most workable procedure appears to be to dewater the sand stratum with a continuous ring of well-points or a gravel filled drainage ditch extending into the top of the clay. Concrete caissons would then be used to underpin the exterior columns; interior columns would be underpinned with jacked piles. The procedure is shown schematically in figure 3-2. Details of certain portions

of the construction procedure are shown in figures 3-3, 3-4, and 3-5.

In principle, any underpinning procedes one column at a time (walls are underpinned in short alternate sections) In underpinning each column, three general steps are normally required:

1. The column is temporarily shored to remove the load from its existing footing or other foundation element.
2. The underpinning is installed. During this phase the building is carefully monitored for any movements as a warning of future difficulties.
3. The column load is transferred to the underpinning, the shoring is removed, and damage to walls, floors, and finish is repaired.

For Building Alpha the site would be prepared before starting any underpinning. The wellpoints or drainage ditches would be installed, the site dewatered to the top of the clay, and a benchmark to rock installed for precise settlement measurements.

The underpinning would then begin by shoring a corner column. This is probably most easily done for this building by installing two needle beams, one on each side of the column, bearing on timber pads over the thick concrete mat. For the exterior columns, the basement walls must be broken out in part to make room for this installation. One form of a needle beam is shown in Fig. 3. A witness mark or settlement observation point would be set in the column and continuous level readings made of its elevation. The column would be continuously maintained at its original elevation by frequent adjustments of the jacks providing the reactions for the

needle beams. The accuracy of the level readings is central to the success of the entire operation and should therefore be made to 0.001 feet with the aid of an optical micrometer.

With the column load removed from its footing (in this case, actually a thickened portion of the mat) the excavation under the footing can begin. An access pit is dug alongside the edge of the mat and a caisson excavated beneath the footing down to the level of the till. Narrow breastboards 4 to 6 inches wide are installed behind corner cleats as the excavation procedes. To help prevent the clay squeezing into the excavation, this work must be done by skilled and experienced workmen using meticulous care; each breastboard must be neatly fitted for good bearing across its entire length against the face of the clay behind.

When the caisson is excavated to the till, it is filled with concrete to within about 6 inches of the bottom of the footing. The breastboards are left in place. In this case, they are all below the water table and there need be no concern that they might rot. High early strength cement should be used in the concrete so that the entire operation can be completed as quickly as possible.

As soon as the concrete has attained a strength sufficient to carry the column load with a reasonable safety factor, the column load is transferred from the needle beams back to the underpinning. This is done by "dry packing" the space between the top of the concrete and the bottom of the footing. All laitance on the upper surface of the caisson is chipped off and the space above it is filled with a dry sand-cement mortar mixed with just enough water to be workable. It is rammed into place a few cubic inches at a time with heavy blows of a 2 x 4. When the dry pack has set, the load is slowly and carefully reduced on the needle beam jacks, which

transfers the column load to the underpinning. A caisson is then installed by the same process under each of the remaining exterior columns to be underpinned. The procedure is shown schematically in figure 3-4.

Underpinning of the interior columns is more easily done by jacking piles against the reaction of the column to be underpinned. The procedure is shown schematically in figure 3-5. The column is first needled as before. The concrete mat is broken out for access and a short tunnel constructed to the corner of the footing. Meticulous care must be used in the tunneling to prevent the earth squeezing in. It may be necessary to grout behind the breastboards to insure that intimate contact is maintained between them and the earth behind.

The next step is to jack steel pipe piles into the ground at the floor of the tunnel using the footing itself as a reaction. The piles proposed for this building have a 90 ton capacity and would be 18 inches in diameter. They will be filled with concrete after jacking is completed.

Bearing plates are installed (not shown in figure 3-5) against the bottom of the footing and a short section of pipe is jacked into the floor of the tunnel. The jacks are then retracted and a second section of pipe set in place and welded to the first. This process is repeated until the bottom of the pile has reached the till at elevation -60 and the jacking load is 150% of design capacity, in this case about 140 tons. The jacks are then removed, and the pile cleaned out and filled with high early strength concrete. When the concrete has set, the jacks are re-installed and the load increased again to 140 tons. A strut

fitted with steel wedges is now installed between the jacking beam at the top of the pile and the bottom of the footing.

The tunnel is now extended to the location of an adjacent pile and the process repeated. Before the wedging strut is placed, however, the first pile is rejacked to 140 tons and rewedged. The second pile is then wedged.

This process is continued for the entire footing, one pile at a time. After the installation of each pile, every pile in the two adjacent rows is rejacked so that some overload is maintained continuously. The amount of the overload may have to be reduced as the last piles in the cluster are installed to avoid raising the column from its original elevation.

If this is to be fixed underpinning, the wedges are then welded, the jacks removed, and the cavity under the footing filled with blown concrete. If the installation is to be adjustable for future small movements, the jacks are double locked and the wedges tack welded to prevent accidental slippage. Permanent access chambers are constructed, and access panels installed in the floor above.

This process is repeated for all other interior columns to be underpinned. It should be emphasized again that careful settlement readings are continuous during the entire operation.

It should not be supposed that this is by any means the only suitable underpinning for this building. After considerable study, it appears to be technically satisfactory and economically competitive, and involves the least risk of the

many techniques studied. The decision to use only partial underpinning is by no means a final one. Its feasibility is, in some measure, dependent on the owner's staff, the form of the construction contract, and many other variables which are only guesses at this time.

The cost of this single underpinning installation is estimated at $450,000 to $500,000. If all of the columns are to be underpinned, that figure will be increased to $950,000 to $1,100,000. $500,000 has been carried in the estimate for total underpinning costs along the Albany Street route. Building Alpha is therefore one major reason why the final construction costs may be well above the estimates given earlier in this section.

It is to be hoped that the above description has conveyed something of the nature of underpinning construction. Difficult and uncertain at best, it will probably always remain more art than science. Small details -- a faulty jack or an unsuspected sand seam -- can have costly and even dangerous consequences. To be done safely, it demands an experienced and specialized contractor and continuous supervision by expert personnel. There is a very real question of the wisdom of attempting it at all on a project which must by law be open to public bid.

VI. CONCLUSIONS

The conclusions of this study may be summarized as follows:

1. Because of the engineering properties of the subsoils and foundation design practice in the area, the water table along the Albany Street alignment cannot be depressed for more than a few feet for periods of greater than a few months without risking substantial interior damage to nearby buildings. It has been concluded that a drawdown of 20 feet is entirely possible in the area because of a pervious sand stratum. If this were sustained for a period of several years, major damage would result, not only to the industrial buildings in the area but to much of the M.I.T. plant as well.

   It is concluded, therefore, that unconventional construction techniques are required along the Albany Street corridor if the roadway is to be depressed to the proposed profile. Some suggested techniques include construction of the highway in short segments using an annual construction cycle; the use of slurry trench wall to maintain the water table outside the excavation; the use of a cellular cofferdam back-filled with an impervious soil for the same purpose; and grouting the sand stratum to delay the depression of the water table.

2. There is an unacceptably high risk of immediate deep shear failure wherever the depth of the Boston clay deposit extends below elevation -50. The risk of

deep shear failure is increasingly greater with increasing depth of clay down to elevation -75, after which additional depths of clay have no significant effect. Even in areas where the bottom of the clay is above -50, there is a real risk of long term failure on a shallower failure circle. It is concluded on the basis of data so far available that it is impossible to construct the highway on the proposed Albany Street alignment and profile by conventional methods without unacceptably high risk of major failure. Unconventional methods which seem plausible include the use of an anchored slab to reduce the total depth of excavation. Prestressed anchors grouted into the rock are more attractive than anchor piles for many reasons. If a conventional boat section must be used, the excavation must be carried out by a slow and expensive "checkerboard" procedure.

3. The safety factor against a shear failure in the bottom of an open excavation for the M.B.T.A. realignment is far too low to consider using cut-and-cover procedures for this construction. It is concluded that there appears to be no practical alternative to tunneling techniques.

4. The Albany Street alignment will require extensive underpinning of adjacent buildings. The total cost of this work is estimated as $1,460,000, but may approach $2,500,000, depending on a number of factors which are unassessable at this time. Much of this work is heavy and difficult; it is strongly questionable whether it should be attempted at all on a publicly bid project.

T35
M Massachusetts. Department
of Public Works.
Interstate route 695, inner belt
highway location restudy. 1967.

DATE	ISSUED TO
1/30/72	Sharon Weinstein (Intl.)